Evaluation of SIRUP with the THALIA Benchmark for Data Integration Systems

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Department of Informatics
University of Zurich

Patrick Ziegler
pziegler@ifi.uzh.ch

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1 Introduction

In this report, source data and query results are presented from the evaluation of the SIRUP approach to personal semantic data integration [Zie07, ZD04] according to the THALIA benchmark for data integration systems [HST04, HST05]. The purpose of this publication is to document concrete data examples as employed for the evaluation of SIRUP according to the THALIA benchmark, together with the corresponding integration results. Detailed information on the SIRUP approach and the employed integration and query language SIQL[1] as well as interpretations of the results of the integration examples are beyond the scope of this report; for pertinent information, we refer the interested reader to [Zie07]. A complete description of all integration conflicts in the THALIA benchmark can be found in [HST04].

In general, the presentation of each THALIA integration case is structured according to the following scheme:

- **Conflict:** First of all, a short description of the respective data integration case is given.
- **Source Data:** Second, the source data for the particular integration case is shown.
- **Conflict Resolution:** Then, a concrete solution to overcome the respective integration issues is illustrated.
- **Result:** Finally, the resulting integrated data is listed.

For the evaluation, the involved data sets are normalized as necessary and annotated so that they comply with the requirements for source data in the SIRUP approach (see [Zie07] for detailed information on these requirements); then, data is assigned to IConcepts which accurately represent the intended meaning of this data. In order to document this preprocessing, this report lists the complete source data for each integration case in the THALIA benchmark in the respective "Source Data" section.

In cases where data examples in this report lead to tabular representations which are too wide to be shown in a single page, we employ a splitting technique to produce several subtables which are narrower in width. This technique is illustrated in the following Table 1; it presents the data of three records in three subtables. Thereby, the dots in the rightmost column of the first two subtables indicate that another subtable follows to present further data which does not fit into the particular subtable. To represent the original relationships between corresponding rows in the different subtables, each row is numbered (0 to 2 in Table 1). In addition, the relationship between the subtables is stated in their table captions.

Table 1: An Example of a Wide Table

	CatalogNumber	CourseTitle	...
0	490	Software-Qualität	...
1	508	Implementierung von Datenbanksystemen	...
2	510	Advanced Software Engineering	...

[1] SIRUP Integration and Query Language

Table 1 – Continued

	InstructorFamilyName	CourseRoom	CreditPoints	BeginDate	...
0	Glinz	BIN 2.A.10	3.0	2007/03/19	...
1	Dittrich	BIN 2.A.01	3.0	2007/03/21	...
2	Gall	BIN 1.D.07	6.0	2007/03/21	...

Table 1 – Continued

	BeginTime	EndTime	CourseType
0	14.00	15.45	Vorlesung
1	10.15	13.45	Vorlesung
2	09.15	12.00	Vorlesung

By following the row numbers on the left hand side of each subtable, the original record data can be reconstructed. Hence, the data presented in our example in Table 1 is equivalent to the following three records:

- r_0 = <490, Software-Qualität, Glinz, BIN 2.A.10, 3.0, 2007/03/19, 14.00, 15.45, Vorlesung>
- r_1 = <508, Implementierung von Datenbanksystemen, Dittrich, BIN 2.A.01, 3.0, 2007/03/21, 10.15, 13.45, Vorlesung>
- r_2 = <510, Advanced Software Engineering, Gall, BIN 1.D.07, 6.0, 2007/03/21, 09.15, 12.00, Vorlesung>

After these introductory remarks, the following sections in this report include the source and result data for the integration cases of the THALIA benchmark for data integration systems in the structure of our presentation scheme.

2 Benchmark Query 1: Synonyms

Conflict: In the first THALIA query, all courses taught by the instructor called "Mark" are requested. The given course data for this query is from the Georgia Institute of Technology[2] and Carnegie Mellon University[3]. The challenge for the data integration system here is to determine that in the course catalog of the Georgia Institute of Technology, the instructor information is in the "Instructor" field, while in the catalog of Carnegie Mellon University, it is in a field called "Lecturer".

Source Data: See Table 2 (IConcept GeorgiaTechCSCourse), Table 3 (IConcept CarnegieMellonCSCourse), and Table 4 (IConcept CarnegieMellonCSLecturer).

[2] http://www.gatech.edu/
[3] http://www.cs.cmu.edu/

Table 2: Georgia Institute of Technology Courses (IConcept GeorgiaTechCSCourse)

	Department	Code	Section	Mode	CRN	Title	...
0	CS	4001	A	L	25727	Computing Society	...
1	CS	4001	B	L	25728	Computing Society	...
2	CS	4001	D	L	25740	Computing Society	...
3	CS	4001	RNZ	LPA	25896	Computing Society	...
4	CS	4210	A	LPA	21996	Adv Operating Systems	...
5	CS	4220	A	LPA	25778	Embedded Systems	...
6	CS	4235	A	LPA	23615	Computer Networking II	...
7	CS	4255	A	L	25779	Intro-Network Management	...
8	CS	4290	A	LPA	20387	Advanced Computer Org	...
9	CS	4330	A	L	21831	Software Applications	...

Table 2 – Continued

	Hours	In	Max	Days	TimeBegin	TimeEnd	Instructor	Room	...
0	3	40	42	TR	0305pm	0425pm	Rugaber	320	...
1	3	41	42	MWF	0105pm	0155pm	Shaw	101	...
2	3	37	42	TR	0435pm	0555pm	Harrold	S204	...
3	3	20	40	TBA	TBA	TBA	Badre	TBA	...
4	3	37	42	MWF	0205pm	0255pm	Smaragdakis	102	...
5	3	24	27	TR	1205pm	0125pm	Pu	320	...
6	3	39	45	TR	0435pm	0555pm	Dovrolis	101	...
7	3	37	40	TR	0935am	1055am	Clark	101	...
8	3	4	10	MWF	0105pm	0155pm	Prvulovic	102	...
9	3	11	15	TR	0805am	0925am	Rugaber	102	...

Table 2 – Continued

	Building	Description	Restrictions	Prerequisites
0	Cherry Emerson	null_no_value	Course restricted: Only class JR SR.	null_no_value
1	Coll of Computing	null_no_value	Course restricted: Only class JR SR.	null_no_value
2	Howey (Physics)	null_no_value	Course restricted: Only class JR SR.	null_no_value
3	null_no_value	Pacific Study Abroad in New Zealand	null_no_value	null_no_value
4	Coll of Computing	null_no_value	null_no_value	Enforced Pre-requisite(s): CS 2200 Or ECE 3055
5	Cherry Emerson	TBA TBA Pu TBA	null_no_value	null_no_value
6	Coll of Computing	null_no_value	null_no_value	Enforced Pre-requisite(s): CS 3251
7	Coll of Computing	null_no_value	null_no_value	Enforced Pre-requisite(s): CS 3251

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	Building	Description	Restrictions	Prerequisites
8	Coll of Computing	null_no_value	null_no_value	Enforced Pre-requisite(s): CS 2200
9	Coll of Computing	TBA TBA Rugaber TBA	null_no_value	null_no_value

Table 3: Carnegie Mellon University Courses (IConcept CarnegieMellonCSCourse)

	Code	Sec	CourseX-Listed	CourseTitle	...
0	15-721*	A	.	Database System Design and Implementation	...
1	15-744*	A	.	Computer Networks	...
2	15-750*	A	.	Graduate Algorithms	...
3	15-780*	A	16-731	Advanced AI Concepts	...
4	15-782	A	15-496	Artificial Neural Networks	...
5	15-785	A	15-485/ 85-485/785	Computational Perception and Scene Analysis	...
6	15-802	A	10-702	Statistical Approaches to Learning and Discovery	...
7	15-812*	A	.	Semantics of Programming Languages	...
8	15-815	A	.	Automated Theorem Proving	...
9	15-818	A4	.	Separation Logic	...
10	15-819	B	.	Specification and Verification	...
11	15-820	A	.	Verification of Concurrent, Reactive, Real-Time Prgrms	...
12	15-820	B	.	Seminar in Software Systems: Queueing Theory and Scheduling	...
13	15-829	F	18-732	Secure Software Systems	...
14	15-845	A	.	Current Research Issues in Computer Systems	...
15	15-859	A	.	Advanced Topics in Theory: Machine Learning Theory	...
16	15-859	K	21-801	Advanced Topics in Theory: Web Structure and Algorithms	...
17	15-864	A	.	Advanced Computer Graphics	...
18	15-887*	A	16-830	Planning, Execution and Learning	...
19	15-889	D	.	Building Speech Recognition Systems	...
20	15-899	B	.	Computational Genomics: From Experimental Data to Systems Biology	...
21	15-998	A	.	Computer Science Practicum Available to CSD PhD Students Only	...

Table 3 – Continued

	Room	Day	TimeBegin	TimeEnd	Units
0	WeH 4615A	MWF	1:30pm	2:50pm	12
1	WeH 5409	F	1:30pm	4:20pm	12
2	WeH 5409	MWF	10:30am	11:50am	12
3	NSH 1305	TR	1:30pm	2:50pm	12

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	Room	Day	TimeBegin	TimeEnd	Units
4	TBA	MW	3:30pm	4:50pm	12
5	SH 422	TR	3:00pm	4:20pm	12
6	WeH 5409	MW	12pm	1:20pm	12
7	WeH 5409	TR	10:30am	11:50am	12
8	WeH 4601	TR	10:30am	11:50am	12
9	WeH 4615A	TR	3:00pm	4:20pm	6
10	WeH 4615A	TR	1:30pm	2:50pm	12
11	WeH 4601	W	3:30pm	4:50pm	6
12	WeH 8220	T	12:00pm	1:50pm	6
13	MW W	null_no_value	12pm	null_no_value	null_no_value
14	WeH 7220	M	12:00pm	1:20pm	2
15	WeH 5409	TR	1:30pm	2:50pm	12
16	WeH 4615A	MW	12:00pm	1:20pm	12
17	WeH 4615A	TR	10:30am	11:50am	12
18	NSH 3002	MW	1:30pm	2:50pm	12
19	WeH 5324	TBA	12pm	null_no_value	null_no_value
20	WeH 5409	TR	9:00am	10:20am	12
21	N/A	N/A	N/A	null_no_value	1-36

Table 4: Carnegie Mellon University Lecturers (IConcept CarnegieMellonCSLecturer)

	Code	Sec	Lecturer
0	15-721*	A	Ailamaki
1	15-744*	A	Zhang
2	15-750*	A	Blum
3	15-780*	A	Atkeson
4	15-782	A	Touretzky
5	15-785	A	Lewicki
6	15-802	A	Lafferty
7	15-802	A	Wasserman
8	15-802	A	Seidenfeld
9	15-812*	A	Brookes
10	15-815	A	Pfenning
11	15-818	A4	Reynolds
12	15-819	B	Clarke
13	15-819	B	Reynolds
14	15-820	A	Clarke
15	15-820	B	Harchol-Balter
16	15-829	F	Song
17	15-829	F	Wing
18	15-845	A	Steenkiste
19	15-859	A	Blum
20	15-859	K	Frieze
21	15-864	A	James
22	15-887*	A	Veloso
23	15-887*	A	Simmons
24	15-889	D	Baker

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	Code	Sec	Lecturer
25	15-889	D	Reddy
26	15-889	D	Singh
27	15-889	D	TBA
28	15-899	B	Bar-Joseph
29	15-998	A	TBA

Conflict Resolution: In SIRUP, cases of synonymy between attributes lead to situations where attributes are connected with the same ontological concepts. In addition, SIRUP users can inspect the textual documentation and the ontological concepts "Lecturer" and "Instructor" are connected to and determine, based on their own interpretations, whether they regard the particular attributes as similar enough to be integrated. In cases where no semantic equivalence is assumed by a user, the corresponding attributes are not integrated but used separately in queries. If, on the other hand, semantic equivalence is given for the respective user, the synonym challenge of our THALIA benchmark query can be resolved using the following SIQL query:

Listing 1: SIQL Solution for THALIA Benchmark Query 1

```
0  select ∗ from (
1          (select ∗ from GeorgiaTechCSCourse)
2          outer union
3          (select c.Code as CRN, c.Sec as Section,
4          Lecturer as Instructor, CourseX−Listed,
5          CourseTitle as Title, Room, Day as Days,
6          TimeBegin, TimeEnd, Units as Hours from
7                  (select ∗ from CarnegieMellonCSCourse) as c
8                  inner join
9                  (select ∗ from CarnegieMellonCSLecturer) as l
10                 on c.Code = l.Code and l.Sec = c.Sec))
11 where instructor = "Mark";
```

Result: Despite the fact that all courses taught by the instructor called "Mark" are requested in this benchmark query, there is *no* instructor called "Mark" in the given THALIA data set. Hence, the query from Listing 1 returns an empty result set. However, to illustrate the integration performed by this query, the presented data in the following table comprises the complete integrated course data.

Table 5: Result Data for SIQL Query from Listing 1

	Department	Code	Section	Mode	CRN	...
0	CS	4001	A	L	25727	...
1	CS	4001	B	L	25728	...
2	CS	4001	D	L	25740	...
3	CS	4001	RNZ	LPA	25896	...
4	CS	4210	A	LPA	21996	...
5	CS	4220	A	LPA	25778	...

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	Department	Code	Section	Mode	CRN	...
6	CS	4235	A	LPA	23615	...
7	CS	4255	A	L	25779	...
8	CS	4290	A	LPA	20387	...
9	CS	4330	A	L	21831	...
10	null_no_attribute	null_no_attribute	A	null_no_attribute	15-721*	...
11	null_no_attribute	null_no_attribute	A	null_no_attribute	15-744*	...
12	null_no_attribute	null_no_attribute	A	null_no_attribute	15-750*	...
13	null_no_attribute	null_no_attribute	A	null_no_attribute	15-780*	...
14	null_no_attribute	null_no_attribute	A	null_no_attribute	15-782	...
15	null_no_attribute	null_no_attribute	A	null_no_attribute	15-785	...
16	null_no_attribute	null_no_attribute	A	null_no_attribute	15-802	...
17	null_no_attribute	null_no_attribute	A	null_no_attribute	15-802	...
18	null_no_attribute	null_no_attribute	A	null_no_attribute	15-802	...
19	null_no_attribute	null_no_attribute	A	null_no_attribute	15-812*	...
20	null_no_attribute	null_no_attribute	A	null_no_attribute	15-815	...
21	null_no_attribute	null_no_attribute	A4	null_no_attribute	15-818	...
22	null_no_attribute	null_no_attribute	B	null_no_attribute	15-819	...
23	null_no_attribute	null_no_attribute	B	null_no_attribute	15-819	...
24	null_no_attribute	null_no_attribute	A	null_no_attribute	15-820	...
25	null_no_attribute	null_no_attribute	B	null_no_attribute	15-820	...
26	null_no_attribute	null_no_attribute	F	null_no_attribute	15-829	...
27	null_no_attribute	null_no_attribute	F	null_no_attribute	15-829	...
28	null_no_attribute	null_no_attribute	A	null_no_attribute	15-845	...
29	null_no_attribute	null_no_attribute	A	null_no_attribute	15-859	...
30	null_no_attribute	null_no_attribute	K	null_no_attribute	15-859	...
31	null_no_attribute	null_no_attribute	A	null_no_attribute	15-864	...
32	null_no_attribute	null_no_attribute	A	null_no_attribute	15-887*	...
33	null_no_attribute	null_no_attribute	A	null_no_attribute	15-887*	...
34	null_no_attribute	null_no_attribute	D	null_no_attribute	15-889	...
35	null_no_attribute	null_no_attribute	D	null_no_attribute	15-889	...
36	null_no_attribute	null_no_attribute	D	null_no_attribute	15-889	...
37	null_no_attribute	null_no_attribute	D	null_no_attribute	15-889	...
38	null_no_attribute	null_no_attribute	B	null_no_attribute	15-899	...
39	null_no_attribute	null_no_attribute	A	null_no_attribute	15-998	...

Table 5 – Continued

	Title	Hours	In	Max	...
0	Computing Society	3	40	42	...
1	Computing Society	3	41	42	...
2	Computing Society	3	37	42	...
3	Computing Society	3	20	40	...
4	Adv Operating Systems	3	37	42	...
5	Embedded Systems	3	24	27	...
6	Computer Networking II	3	39	45	...
7	Intro-Network Management	3	37	40	...
8	Advanced Computer Org	3	4	10	...

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	Title	Hours	In	Max	...
9	Software Applications	3	11	15	...
10	Database System Design and Implementation	12	null_no_attribute	null_no_attribute	...
11	Computer Networks	12	null_no_attribute	null_no_attribute	...
12	Graduate Algorithms	12	null_no_attribute	null_no_attribute	...
13	Advanced AI Concepts	12	null_no_attribute	null_no_attribute	...
14	Artificial Neural Networks	12	null_no_attribute	null_no_attribute	...
15	Computational Perception and Scene Analysis	12	null_no_attribute	null_no_attribute	...
16	Statistical Approaches to Learning and Discovery	12	null_no_attribute	null_no_attribute	...
17	Statistical Approaches to Learning and Discovery	12	null_no_attribute	null_no_attribute	...
18	Statistical Approaches to Learning and Discovery	12	null_no_attribute	null_no_attribute	...
19	Semantics of Programming Languages	12	null_no_attribute	null_no_attribute	...
20	Automated Theorem Proving	12	null_no_attribute	null_no_attribute	...
21	Separation Logic	6	null_no_attribute	null_no_attribute	...
22	Specification and Verification	12	null_no_attribute	null_no_attribute	...
23	Specification and Verification	12	null_no_attribute	null_no_attribute	...
24	Verification of Concurrent, Reactive, Real-Time Prgrms	6	null_no_attribute	null_no_attribute	...
25	Seminar in Software Systems: Queueing Theory and Scheduling	6	null_no_attribute	null_no_attribute	...
26	Secure Software Systems	null_no_value	null_no_attribute	null_no_attribute	...
27	Secure Software Systems	null_no_value	null_no_attribute	null_no_attribute	...
28	Current Research Issues in Computer Systems	2	null_no_attribute	null_no_attribute	...
29	Advanced Topics in Theory: Machine Learning Theory	12	null_no_attribute	null_no_attribute	...
30	Advanced Topics in Theory: Web Structure and Algorithms	12	null_no_attribute	null_no_attribute	...
31	Advanced Computer Graphics	12	null_no_attribute	null_no_attribute	...
32	Planning, Execution and Learning	12	null_no_attribute	null_no_attribute	...
33	Planning, Execution and Learning	12	null_no_attribute	null_no_attribute	...
34	Building Speech Recognition Systems	null_no_value	null_no_attribute	null_no_attribute	...
35	Building Speech Recognition Systems	null_no_value	null_no_attribute	null_no_attribute	...
36	Building Speech Recognition Systems	null_no_value	null_no_attribute	null_no_attribute	...
37	Building Speech Recognition Systems	null_no_value	null_no_attribute	null_no_attribute	...
38	Computational Genomics: From Experimental Data to Systems Biology	12	null_no_attribute	null_no_attribute	...
39	Computer Science Practicum Available to CSD PhD Students Only	1-36	null_no_attribute	null_no_attribute	...

Table 5 – Continued

	Days	TimeBegin	TimeEnd	Instructor	Room	...
0	TR	0305pm	0425pm	Rugaber	320	...
1	MWF	0105pm	0155pm	Shaw	101	...
2	TR	0435pm	0555pm	Harrold	S204	...
3	TBA	TBA	TBA	Badre	TBA	...
4	MWF	0205pm	0255pm	Smaragdakis	102	...
5	TR	1205pm	0125pm	Pu	320	...
6	TR	0435pm	0555pm	Dovrolis	101	...
7	TR	0935am	1055am	Clark	101	...
8	MWF	0105pm	0155pm	Prvulovic	102	...
9	TR	0805am	0925am	Rugaber	102	...
10	MWF	1:30pm	2:50pm	Ailamaki	WeH 4615A	...
11	F	1:30pm	4:20pm	Zhang	WeH 5409	...
12	MWF	10:30am	11:50am	Blum	WeH 5409	...
13	TR	1:30pm	2:50pm	Atkeson	NSH 1305	...
14	MW	3:30pm	4:50pm	Touretzky	TBA	...
15	TR	3:00pm	4:20pm	Lewicki	SH 422	...
16	MW	12pm	1:20pm	Lafferty	WeH 5409	...
17	MW	12pm	1:20pm	Seidenfeld	WeH 5409	...
18	MW	12pm	1:20pm	Wasserman	WeH 5409	...
19	TR	10:30am	11:50am	Brookes	WeH 5409	...
20	TR	10:30am	11:50am	Pfenning	WeH 4601	...
21	TR	3:00pm	4:20pm	Reynolds	WeH 4615A	...
22	TR	1:30pm	2:50pm	Clarke	WeH 4615A	...
23	TR	1:30pm	2:50pm	Reynolds	WeH 4615A	...
24	W	3:30pm	4:50pm	Clarke	WeH 4601	...
25	T	12:00pm	1:50pm	Harchol-Balter	WeH 8220	...
26	null_no_value	12pm	null_no_value	Song	MW W	...
27	null_no_value	12pm	null_no_value	Wing	MW W	...
28	M	12:00pm	1:20pm	Steenkiste	WeH 7220	...
29	TR	1:30pm	2:50pm	Blum	WeH 5409	...
30	MW	12:00pm	1:20pm	Frieze	WeH 4615A	...
31	TR	10:30am	11:50am	James	WeH 4615A	...
32	MW	1:30pm	2:50pm	Simmons	NSH 3002	...
33	MW	1:30pm	2:50pm	Veloso	NSH 3002	...
34	TBA	12pm	null_no_value	Baker	WeH 5324	...
35	TBA	12pm	null_no_value	Reddy	WeH 5324	...
36	TBA	12pm	null_no_value	Singh	WeH 5324	...
37	TBA	12pm	null_no_value	TBA	WeH 5324	...
38	TR	9:00am	10:20am	Bar-Joseph	WeH 5409	...
39	N/A	N/A	null_no_value	TBA	N/A	...

Table 5 – Continued

	Building	Description	Restrictions	...
0	Cherry Emerson	null_no_value	Course restricted: Only class JR SR.	...
1	Coll of Computing	null_no_value	Course restricted: Only class JR SR.	...

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	Building	Description	Restrictions	...
2	Howey (Physics)	null_no_value	Course restricted: Only class JR SR.	...
3	null_no_value	Pacific Study Abroad in New Zealand	null_no_value	...
4	Coll of Computing	null_no_value	null_no_value	...
5	Cherry Emerson	TBA TBA Pu TBA	null_no_value	...
6	Coll of Computing	null_no_value	null_no_value	...
7	Coll of Computing	null_no_value	null_no_value	...
8	Coll of Computing	null_no_value	null_no_value	...
9	Coll of Computing	TBA TBA Rugaber TBA	null_no_value	...
10	null_no_attribute	null_no_attribute	null_no_attribute	...
11	null_no_attribute	null_no_attribute	null_no_attribute	...
12	null_no_attribute	null_no_attribute	null_no_attribute	...
13	null_no_attribute	null_no_attribute	null_no_attribute	...
14	null_no_attribute	null_no_attribute	null_no_attribute	...
15	null_no_attribute	null_no_attribute	null_no_attribute	...
16	null_no_attribute	null_no_attribute	null_no_attribute	...
17	null_no_attribute	null_no_attribute	null_no_attribute	...
18	null_no_attribute	null_no_attribute	null_no_attribute	...
19	null_no_attribute	null_no_attribute	null_no_attribute	...
20	null_no_attribute	null_no_attribute	null_no_attribute	...
21	null_no_attribute	null_no_attribute	null_no_attribute	...
22	null_no_attribute	null_no_attribute	null_no_attribute	...
23	null_no_attribute	null_no_attribute	null_no_attribute	...
24	null_no_attribute	null_no_attribute	null_no_attribute	...
25	null_no_attribute	null_no_attribute	null_no_attribute	...
26	null_no_attribute	null_no_attribute	null_no_attribute	...
27	null_no_attribute	null_no_attribute	null_no_attribute	...
28	null_no_attribute	null_no_attribute	null_no_attribute	...
29	null_no_attribute	null_no_attribute	null_no_attribute	...
30	null_no_attribute	null_no_attribute	null_no_attribute	...
31	null_no_attribute	null_no_attribute	null_no_attribute	...
32	null_no_attribute	null_no_attribute	null_no_attribute	...
33	null_no_attribute	null_no_attribute	null_no_attribute	...
34	null_no_attribute	null_no_attribute	null_no_attribute	...
35	null_no_attribute	null_no_attribute	null_no_attribute	...
36	null_no_attribute	null_no_attribute	null_no_attribute	...
37	null_no_attribute	null_no_attribute	null_no_attribute	...
38	null_no_attribute	null_no_attribute	null_no_attribute	...
39	null_no_attribute	null_no_attribute	null_no_attribute	...

Table 5 – Continued

	Prerequisites	CourseX-Listed
0	null_no_value	null_no_attribute
1	null_no_value	null_no_attribute
2	null_no_value	null_no_attribute
3	null_no_value	null_no_attribute

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	Prerequisites	CourseX-Listed
4	Enforced Pre-requisite(s): CS 2200 Or ECE 3055	null_no_attribute
5	null_no_value	null_no_attribute
6	Enforced Pre-requisite(s): CS 3251	null_no_attribute
7	Enforced Pre-requisite(s): CS 3251	null_no_attribute
8	Enforced Pre-requisite(s): CS 2200	null_no_attribute
9	null_no_value	null_no_attribute
10	null_no_attribute	.
11	null_no_attribute	.
12	null_no_attribute	.
13	null_no_attribute	16-731
14	null_no_attribute	15-496
15	null_no_attribute	15-485/ 85-485/785
16	null_no_attribute	10-702
17	null_no_attribute	10-702
18	null_no_attribute	10-702
19	null_no_attribute	.
20	null_no_attribute	.
21	null_no_attribute	.
22	null_no_attribute	.
23	null_no_attribute	.
24	null_no_attribute	.
25	null_no_attribute	.
26	null_no_attribute	18-732
27	null_no_attribute	18-732
28	null_no_attribute	.
29	null_no_attribute	.
30	null_no_attribute	21-801
31	null_no_attribute	.
32	null_no_attribute	16-830
33	null_no_attribute	16-830
34	null_no_attribute	.
35	null_no_attribute	.
36	null_no_attribute	.
37	null_no_attribute	.
38	null_no_attribute	.
39	null_no_attribute	.

3 Benchmark Query 2: Simple Mapping

Conflict: For the second THALIA benchmark query, all database courses that meet at 1:30pm on any given day have to be retrieved. The two data sets for this are the courses from the University of Massachusetts (Boston)[4] and, as in the benchmark query 1, from the Carnegie Mellon University. The issue to be coped with in benchmark query 2 is given by related attributes in different schemas that differ by a mathematical transformation. More precisely, a conversion of time represented in a 12

[4] http://www.umb.edu/

hours format in the Carnegie Mellon University data into a 24 hours format as used by the University of Massachusetts is needed.

Source Data: See Table 2 (IConcept GeorgiaTechCSCourse) and Table 6 (IConcept UniMassachusettsCSCourse).

Table 6: University of Massachusetts Courses (IConcept UniMassachusettsCSCourse)

	Code	SchedNum	Sec	Title	Credits	...
0	CS105	261194	1	Computer Concepts	3.0	...
1	CS105	261201	2	Computer Concepts	3.0	...
2	CS109	.	1	Computer Programming for Engineers	3.0	...
3	CS110	261215	1	JAVA Intro prog	4.0	...
4	CS110	261215	1d	JAVA Intro prog	4.0	...
5	CS110	261222	2	JAVA Intro prog	4.0	...
6	CS110	261222	2d	JAVA Intro prog	4.0	...
7	CS110	261229	3	JAVA Intro prog	4.0	...
8	CS110	261229	3d	JAVA Intro prog	4.0	...
9	CS110	261236	4	JAVA Intro prog	4.0	...
10	CS110	261236	4d	JAVA Intro prog	4.0	...
11	CS110	261243	5	JAVA Intro prog	4.0	...
12	CS110	261243	5d	JAVA Intro prog	4.0	...
13	CS119	261264	1	Computer Language Supplement	2.0	...
14	CS210	261278	1	Inter Comput/JAVA	4.0	...
15	CS240	261299	1	Programming in C	3.0	...
16	CS240	.	.	Programming in C	3.0	...
17	CS241	261320	1	CompOrganizationArchitecture	3.0	...
18	CS241	261320	1d	CompOrganizationArchitecture	3.0	...
19	CS241	261327	2	CompOrganizationArchitecture	3.0	...
20	CS241	261327	2d	CompOrganizationArchitecture	3.0	...
21	CS241	261334	3	CompOrganizationArchitecture	3.0	...
22	CS241	261334	3d	CompOrganizationArchitecture	3.0	...
23	CS310	261369	1	Advanced Algorithms Data Structures	3.0	...
24	CS L320	281179	1	Applied Discrete Mathematics	3.0	...
25	CS410	261397	1	Intro to Software Engineering	3.0	...
26	CS420	274655	1	Introduction to Theory of Computation	3.0	...
27	CS430	261425	1	Database Management	3.0	...
28	CS444	281634	1	Intro to Operating Systems	3.0	...
29	CS445	261439	1	Real Time Systems	3.0	...
30	CS446	274669	1	Intro to Internetworking	3.0	...
31	CS450	261453	1	Higher Level Lang.	3.0	...
32	CS451	261467	1	Compilers I	3.0	...
33	CS470	261481	1	Intro. Artificial Intelligence	3.0	...
34	CS485	274683	1	Social Issues in CS	3.0	...
35	CS615	205145	1	User Interface Design	3.0	...
36	CS622	274697	1	Theory of Formal Language	3.0	...
37	CS630	205159	1	Database Management	3.0	...
38	CS634	205173	1	Architecture of Database	3.0	...
39	CS644	205201	1	Operating Systems	3.0	...
40	CS651	274711	1	Compilers I	3.0	...
41	CS670	205229	1	Artificial Intelligence	3.0	...

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	Code	SchedNum	Sec	Title	Credits	...
42	CS680	205243	1	Obj. Orient Dsgn Prgm	3.0	...
43	CS680	205250	2	Obj. Orient Dsgn Prgm	3.0	...
44	CS683	205264	1	Obj. Orient Software Development	3.0	...
45	CS683	205271	2	Obj. Orient Software Development	3.0	...
46	CS683	205278	3	Obj. Orient Software Development	3.0	...
47	CS697	281060	1	Special Topics: Wireless Networking	3.0	...

Table 6 – Continued

	Room	Days	TimeBegin	TimeEnd	InstructorFirstName	...
0	M-2-420	T Th	13:30	14:15	Jonathan	...
1	S-2-066	T Th	16:00	17:15	Jonathan	...
2	.	.	(on-line)	(on-line)	Ruth	...
3	M-1-409	M W	19:00	20:15	Gabriel	...
4	HUL042	M	20:30	21:20	Staff	...
5	M-1-409	M W	19:00	20:15	Gabriel	...
6	HUL042	W	20:30	21:20	Staff	...
7	M-1-409	Tu Th	11:30	12:45	Ethan	...
8	HUL042	Tu	10:00	10:50	Staff	...
9	M-1-409	Tu Th	11:30	12:45	Ethan	...
10	HUL042	Th	10:00	10:50	Staff	...
11	M-1-409	Tu Th	11:30	12:45	Ethan	...
12	HUL042	Tu	13:00	13:50	Staff	...
13	.	.	.	.	Staff	...
14	M-1-207	M W	17:30	18:45	Robert	...
15	S-1-006	M W	16:00	17:15	Robert	...
16	.	.	On-Line	On-Line	Ruth	...
17	M-1-608	M W	19:00	20:15	Robert	...
18	S-2-064	M	17:30	18:45	Staff	...
19	M-1-608	M W	19:00	20:15	Robert	...
20	S-1-006	W	17:30	18:45	Staff	...
21	M-1-608	M W	19:00	20:15	Robert	...
22	S-1-006	W	20:30	21:45	Staff	...
23	M-1-213	Tu Th	19:00	20:15	John	...
24	W-1-047	Tu Th	16:00	17:15	Kenneth	...
25	M-1-428	M W	16:00	17:15	Marc	...
26	W-1-004	M W	17:30	18:45	Peter	...
27	M-3-407	M W	16:00	17:15	Patrick	...
28	W-1-041	Tu Th	16:00	17:15	Elizabeth	...
29	S-2-063	M W	20:30	21:45	Ron	...
30	W-1-009	Tu Th	19:00	20:15	Nabil	...
31	M-1-614	Tu Th	19:00	20:15	Paul	...
32	S-2-064	Tu Th	17:30	18:45	Carl	...
33	M-1-619	M W	19:00	20:15	Marc	...
34	S-2-062	M W	16:00	17:15	Edward	...
35	M-1-617	Tu Th	19:00	20:15	Gabriel	...
36	S-2-062	Tu Th	16:00	17:15	Dan	...

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	Room	Days	TimeBegin	TimeEnd	InstructorFirstName	...
37	M-3-407	M W	16:00	17:15	Patrick	...
38	M-1-207	M W	19:00	20:15	Patrick	...
39	W-1-058	Tu Th	17:30	18:45	Elizabeth	...
40	S-2-064	Tu Th	17:30	18:45	Carl	...
41	M-1-619	M W	19:00	20:15	Marc	...
42	M-2-415	M W	17:30	18:45	Michael	...
43	W-1-063	Tu Th	16:00	17:15	Michael	...
44	S-2-062	M W	19:00	20:15	Michael	...
45	M-1-619	M W	17:30	18:45	William	...
46	M-2-420	Tu Th	14:30	15:45	Ethan	...
47	S-2-062	Tu Th	20:30	21:45	Nabil	...

Table 6 – Continued

	InstructorLastName
0	Krentel
1	Krentel
2	Maulucci
3	Rodriguez
4	Staff
5	Rodriguez
6	Staff
7	Bolker
8	Staff
9	Bolker
10	Staff
11	Bolker
12	Staff
13	Staff
14	Cohen
15	Wilson
16	Maulucci
17	Wilson
18	Staff
19	Wilson
20	Staff
21	Wilson
22	Staff
23	Mayer
24	Newman
25	Pomplun
26	Fejer
27	O'Neil
28	O'Neil
29	Cheung
30	Hinnawi
31	Robertson

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	InstructorLastName
32	Offner
33	Pomplun
34	Robins
35	Spitz
36	Simovici
37	O'Neil
38	O'Neil
39	O'Neil
40	Offner
41	Pomplun
42	Weiss
43	Weiss
44	Weiss
45	Cambell
46	Bolker
47	Hinnawi

Conflict Resolution: Attribute conversions, as concerned by the THALIA benchmark query 2, are covered by the extensible set of attribute transformation functions in SIRUP (see [Zie07]). Hence, the requested time format conversion can be done by an appropriate function; it is provided by the Java class ch.uzh.ifi.sirup.siql.functions.attribute.H24to12 in our case. This function takes a 24 hour time format string as an input and produces a string represented in a 12 hour format. In case that the given input is already in a 12 hour format, no changes occur. Before the functionality of this class can be used in SIQL, the class must be registered to SIRUP:

Listing 2: Registering the Attribute Transformation Function h24to12 with SIQL

```
0  create function h24to12
1  using class ch.uzh.ifi.sirup.siql.functions.attribute.H24to12;
```

With the new function h24to12, the integration task of THALIA benchmark query 2 can be done based on the three IConcepts CarnegieMellonCSCourse, CarnegieMellonCSLecturer, and UniMassachusettsCSCourse with the following SIQL query:

Listing 3: SIQL Solution for THALIA Benchmark Query 2

```
0  select * from (
1          (select c.Code, c.Sec, CourseX-Listed, CourseTitle as Title,
2          Room, Day as Days, TimeBegin, TimeEnd, Units,
3          Lecturer as InstructorLastName from
4                  (select * from CarnegieMellonCSCourse) as c
5                  inner join
6                  (select * from CarnegieMellonCSLecturer) as l
7                  on c.Code = l.Code and l.Sec = c.Sec)
8          outer union
9          (select * from UniMassachusettsCSCourse))
10 where h24to12(TimeBegin) = "1:30pm";
```

Result: The requested information on all database courses that meet at 1:30pm on any given day is shown in the following table (note the time information in attribute "TimeBegin"):

Table 7: Result Data for SIQL Query from Listing 3

	Code	Sec	CourseX-Listed	Title	Room	...
0	15-721*	A	.	Database System Design and Implementation	WeH 4615A	...
1	15-744*	A	.	Computer Networks	WeH 5409	...
2	15-780*	A	16-731	Advanced AI Concepts	NSH 1305	...
3	15-819	B	.	Specification and Verification	WeH 4615A	...
4	15-819	B	.	Specification and Verification	WeH 4615A	...
5	15-859	A	.	Advanced Topics in Theory: Machine Learning Theory	WeH 5409	...
6	15-887*	A	16-830	Planning, Execution and Learning	NSH 3002	...
7	15-887*	A	16-830	Planning, Execution and Learning	NSH 3002	...
8	CS105	1	null_no_attribute	Computer Concepts	M-2-420	...

Table 7 – Continued

	Days	TimeBegin	TimeEnd	Units	InstructorLastName	...
0	MWF	1:30pm	2:50pm	12	Ailamaki	...
1	F	1:30pm	4:20pm	12	Zhang	...
2	TR	1:30pm	2:50pm	12	Atkeson	...
3	TR	1:30pm	2:50pm	12	Clarke	...
4	TR	1:30pm	2:50pm	12	Reynolds	...
5	TR	1:30pm	2:50pm	12	Blum	...
6	MW	1:30pm	2:50pm	12	Simmons	...
7	MW	1:30pm	2:50pm	12	Veloso	...
8	T Th	13:30	14:15	null_no_attribute	Krentel	...

Table 7 – Continued

	SchedNum	Credits	InstructorFirstName
0	null_no_attribute	null_no_attribute	null_no_attribute
1	null_no_attribute	null_no_attribute	null_no_attribute
2	null_no_attribute	null_no_attribute	null_no_attribute
3	null_no_attribute	null_no_attribute	null_no_attribute
4	null_no_attribute	null_no_attribute	null_no_attribute
5	null_no_attribute	null_no_attribute	null_no_attribute
6	null_no_attribute	null_no_attribute	null_no_attribute
7	null_no_attribute	null_no_attribute	null_no_attribute
8	261194	3.0	Jonathan

4 Benchmark Query 3: Union Types

Conflict: In the third THALIA query, all courses with the string "Data Structures" in their title are requested. The given course data for this query is from the University of Maryland[5] and Brown University[6]. The challenge for the data integration system here is to map a single string to a composite value which consists of an external link (URL), the course title as well as of day and time information.

Source Data: See Table 8 (IConcept UniMarylandCSCourse), Table 9 (IConcept UniMarylandCS-CourseSection), Table 10 (IConcept UniMarylandCSCourseSectionEvent), and Table 11 (IConcept BrownUniCSCourse).

Table 8: University of Maryland Courses (IConcept UniMarylandCSCourse)

	Code	CourseName	Credits	GradeMethod
0	CMSC102	Introduction to Information Technology	(3 credits)	REG/P-F/AUD.
1	CMSC114	Computer Science I	(4 credits)	REG/P-F/AUD.
2	CMSC311	Computer Organization	(3 credits)	REG.
3	CMSC330	Organization of Programming Languages	(3 credits)	REG.
4	CMSC390	Honors Paper	(3 credits)	REG. Individual Instruction course: contact department or instructor to obtain section number.
5	CMSC411	Computer Systems Architecture	(3 credits)	REG.
6	CMSC412	Operating Systems	(4 credits)	REG. CORE Capstone (CS) Course.
7	CMSC420	Data Structures	(3 credits)	REG.
8	CMSC421	Introduction to Artificial Intelligence	(3 credits)	REG.
9	CMSC424	Database Design	(3 credits)	REG. CORE Capstone (CS) Course.
10	CMSC426	Image Processing	(3 credits)	REG.
11	CMSC427	Computer Graphics	(3 credits)	REG.
12	CMSC430	Theory of Language Translation	(3 credits)	REG.
13	CMSC433	Programming Language Technologies and Paradigms	(3 credits)	REG.
14	CMSC434	Introduction to Human-Computer Interaction	(3 credits)	REG.
15	CMSC435	Software Engineering	(3 credits)	REG. CORE Capstone (CS) Course.
16	CMSC450	Logic for Computer Science	(3 credits)	REG.
17	CMSC451	Design and Analysis of Computer Algorithms	(3 credits)	REG.

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[5] http://www.cs.umd.edu

[6] http://www.cs.brown.edu

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	Code	CourseName	Credits	GradeMethod
18	CMSC456	Cryptology	(3 credits)	null_no_value
19	CMSC460	Computational Methods	(3 credits)	REG.
20	CMSC466	Introduction to Numerical Analysis I	(3 credits)	REG.
21	CMSC475	Combinatorics and Graph Theory	(3 credits)	REG.
22	CMSC498A	Special Problems in Computer Science	(1-3 credits)	REG. Individual Instruction course: contact department or instructor to obtain section number.
23	CMSC498W	Special Problems in Computer Science: Semantic Web	(3 credits)	REG.
24	CMSC598	Practical Training	(1 credit)	S-F. Individual Instruction course: contact department or instructor to obtain section number.
25	CMSC661	Scientific Computing II	(3 credits)	REG.
26	CMSC664	Advanced Scientific Computing II	(3 credits)	REG.
27	CMSC666	Numerical Analysis I	(3 credits)	REG/AUD.
28	CMSC667	Numerical Analysis II	(3 credits)	REG/AUD.
29	CMSC711	Computer Networks	(3 credits)	REG/AUD.
30	CMSC723	Natural Language Processing	(3 credits)	REG/AUD.
31	CMSC724	Database Management Systems	(3 credits)	REG/AUD.
32	CMSC726	Machine Learning	(3 credits)	REG/AUD.
33	CMSC733	Computer Processing of Pictorial Information	(3 credits)	REG/AUD.
34	CMSC740	Advanced Computer Graphics	(3 credits)	REG/AUD.
35	CMSC751	Parallel Algorithms	(3 credits)	REG/AUD.
36	CMSC798	Graduate Seminar in Computer Science	(1-3 credits)	REG/AUD. Individual Instruction course: contact department or instructor to obtain section number.
37	CMSC799	Master's Thesis Research	(1-6 credits)	REG/S-F. Individual Instruction course: contact department or instructor to obtain section number.
38	CMSC818S	Advanced Topics in Computer Systems: Grid Computing	(3 credits)	REG/AUD.
39	CMSC828A	Advanced Topics in Information Processing	(1-3 credits)	REG/AUD. Individual Instruction course: contact department or instructor to obtain section number.
40	CMSC828C	Advanced Topics in Information Processing: Human Factors in Computer and Information Systems	(3 credits)	REG.
41	CMSC828O	Advanced Topics in Information Processing	(3 credits)	REG/AUD.

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	Code	CourseName	Credits	GradeMethod
42	CMSC828R	Advanced Topics in Information Processing: Medical Image Processing and Understanding	(3 credits)	REG/AUD.
43	CMSC838A	Advanced Topics in Programming Languages	(1-3 credits)	REG/AUD. Individual Instruction course: contact department or instructor to obtain section number.
44	CMSC838G	Advanced Topics in Programming Languages: New Devices for New Interactions	(3 credits)	null_no_value
45	CMSC838I	Advanced Topics in Programming Languages: HOW TO DO RESEARCH	(1 credit)	REG/AUD.
46	CMSC838P	Advanced Topics in Programming Languages: Software Engineering: Remote Analysis and Measurement of Software Systems	(3 credits)	REG/AUD.
47	CMSC838T	Advanced Topics in Programming Languages: Systems Software for High Performance Computing, Emphasis on Bioinformatic Applications	(3 credits)	REG/AUD.
48	CMSC838Z	Advanced Topics in Programming Languages	(3 credits)	REG/AUD.
49	CMSC858A	Advanced Topics in Theory of Computing	(1-3 credits)	REG/AUD. Individual Instruction course: contact department or instructor to obtain section number.
50	CMSC858K	Advanced Topics in Theory of Computing: Advanced Topics in Cryptography	(3 credits)	null_no_value
51	CMSC878A	Advanced Topics in Numerical Methods	(1-3 credits)	REG/AUD. Individual Instruction course: contact department or instructor to obtain section number.

Table 9: University of Maryland Course Sections (IConcept UniMarylandCSCourseSection)

	Code	TitleCode	Instructor	Seats	Open	Waitlist
0	CMSC102	0101(13434)	null_no_value	null_no_value	null_no_value	null_no_value
1	CMSC102	0201(13435)	null_no_value	null_no_value	null_no_value	null_no_value
2	CMSC102	0301(13436)	null_no_value	null_no_value	null_no_value	null_no_value
3	CMSC114	0101(13446)	Emad	25	0	0
4	CMSC114	0102(13447)	Emad	25	0	0
5	CMSC114	0201(13448)	Maybury	25	0	0
6	CMSC114	0203(13452)	Maybury	30	2	0

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	Code	TitleCode	Instructor	Seats	Open	Waitlist
7	CMSC114	0101(13461)	Bederson	25	0	0
8	CMSC114	0102(13462)	Bederson	25	0	0
9	CMSC114	0103(13463)	Bederson	25	0	0
10	CMSC114	0201(13464)	Padua-Perez	25	0	0
11	CMSC114	0301(13465)	Padua-Perez	25	0	0
12	CMSC114	0401(13466)	Padua-Perez	25	0	0
13	CMSC114	0101(13477)	Tjaden	25	0	0
14	CMSC114	0102(13478)	Tjaden	25	0	0
15	CMSC114	0201(13479)	Tjaden	25	6	0
16	CMSC114	0202(13480)	Tjaden	25	0	0
17	CMSC114	0301(13481)	Tjaden	25	0	0
18	CMSC114	0302(13482)	Tjaden	25	0	0
19	CMSC114	0101(13492)	null_no_value	null_no_value	null_no_value	null_no_value
20	CMSC114	0102(13493)	null_no_value	null_no_value	null_no_value	null_no_value
21	CMSC114	0201(13494)	null_no_value	null_no_value	null_no_value	null_no_value
22	CMSC114	0202(13495)	null_no_value	null_no_value	null_no_value	null_no_value
23	CMSC311	0101(13580)	Arbaugh	60	14	0
24	CMSC311	0201(13581)	Arbaugh	60	0	0
25	CMSC330	0101(13591)	Herman	25	0	0
26	CMSC330	0102(13592)	Herman	25	8	0
27	CMSC330	0201(13593)	Herman	25	0	0
28	CMSC330	0202(13594)	Herman	25	0	0
29	CMSC330	0301(13595)	Herman	25	0	0
30	CMSC330	0302(13596)	Herman	25	0	0
31	CMSC330	0101(13606)	null_no_value	null_no_value	null_no_value	null_no_value
32	CMSC330	0201(13607)	Emad	50	0	0
33	CMSC330	0301(13608)	Emad	60	0	0
34	CMSC411	0101(13679)	null_no_value	null_no_value	null_no_value	null_no_value
35	CMSC411	0201(13680)	null_no_value	null_no_value	null_no_value	null_no_value
36	CMSC412	0101(13690)	null_no_value	null_no_value	null_no_value	null_no_value
37	CMSC412	0102(13691)	null_no_value	null_no_value	null_no_value	null_no_value
38	CMSC412	0201(13692)	null_no_value	null_no_value	null_no_value	null_no_value
39	CMSC412	0202(13693)	null_no_value	null_no_value	null_no_value	null_no_value
40	CMSC412	0101(13703)	null_no_value	null_no_value	null_no_value	null_no_value
41	CMSC420	0101(13713)	null_no_value	null_no_value	null_no_value	null_no_value
42	CMSC420	0201(13714)	null_no_value	null_no_value	null_no_value	null_no_value
43	CMSC421	0101(13724)	null_no_value	null_no_value	null_no_value	null_no_value
44	CMSC424	0101(13734)	null_no_value	null_no_value	null_no_value	null_no_value
45	CMSC424	0201(13735)	Shapiro	50	6	0
46	CMSC426	0101(13744)	Jacobs	50	15	0
47	CMSC427	0101(13754)	null_no_value	null_no_value	null_no_value	null_no_value
48	CMSC430	0101(13764)	null_no_value	null_no_value	null_no_value	null_no_value
49	CMSC433	0101(13774)	null_no_value	null_no_value	null_no_value	null_no_value
50	CMSC434	0101(13784)	null_no_value	null_no_value	null_no_value	null_no_value
51	CMSC434	0201(13785)	null_no_value	null_no_value	null_no_value	null_no_value
52	CMSC435	0101(13795)	null_no_value	null_no_value	null_no_value	null_no_value
53	CMSC435	0201(13796)	Memon	40	2	0
54	CMSC435	0301(13797)	null_no_value	null_no_value	null_no_value	null_no_value
55	CMSC450	0101(13806)	Lopez-Escobar	25	3	0
56	CMSC451	0101(13816)	Srinivasan	50	18	0

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	Code	TitleCode	Instructor	Seats	Open	Waitlist
57	CMSC456	0101(13826)	null_no_value	null_no_value	null_no_value	null_no_value
58	CMSC456	0201(13827)	Washington	45	0	0
59	CMSC460	0101(13837)	Wolfe	22	3	0
60	CMSC460	0201(13838)	null_no_value	null_no_value	null_no_value	null_no_value
61	CMSC466	0101(13848)	Cooper	25	0	0
62	CMSC475	0101(13858)	Healy	27	7	0
63	CMSC498A	0101(14750)	null_no_value	null_no_value	null_no_value	null_no_value
64	CMSC498W	0101(13929)	null_no_value	null_no_value	null_no_value	null_no_value
65	CMSC661	0101(14001)	null_no_value	null_no_value	null_no_value	null_no_value
66	CMSC664	0101(14011)	null_no_value	null_no_value	null_no_value	null_no_value
67	CMSC666	0101(14021)	Osborn	30	19	0
68	CMSC667	0101(14031)	Liu	25	17	0
69	CMSC711	0101(14041)	Bhattacharjee	20	0	0
70	CMSC723	0101(14051)	null_no_value	null_no_value	null_no_value	null_no_value
71	CMSC724	0101(14061)	null_no_value	null_no_value	null_no_value	null_no_value
72	CMSC726	0101(14071)	Getoor	40	9	0
73	CMSC733	0101(14737)	Aloimonos	20	4	0
74	CMSC740	0101(14072)	Varshney	30	2	0
75	CMSC751	0101(59774)	null_no_value	null_no_value	null_no_value	null_no_value
76	CMSC818S	0101(14327)	Sussman	30	18	0
77	CMSC828C	0101(59745)	null_no_value	null_no_value	null_no_value	null_no_value
78	CMSC828O	0101(59761)	null_no_value	null_no_value	null_no_value	null_no_value
79	CMSC828R	0101(59764)	Chellappa	30	15	0
80	CMSC838G	0101(14469)	Guimbretiere	20	15	0
81	CMSC838I	0101(14479)	null_no_value	null_no_value	null_no_value	null_no_value
82	CMSC838P	0101(14489)	null_no_value	null_no_value	null_no_value	null_no_value
83	CMSC838T	0101(14499)	null_no_value	null_no_value	null_no_value	null_no_value
84	CMSC838Z	0101(14509)	null_no_value	null_no_value	null_no_value	null_no_value
85	CMSC858A	0101(14591)	null_no_value	null_no_value	null_no_value	null_no_value
86	CMSC858K	0101(14601)	Katz	30	9	0

Table 10: University of Maryland Course Section Events (IConcept UniMarylandCSCourseSectionEvent)

	Code	TitleCode	Days	TimeBegin	TimeEnd	Room
0	CMSC102	0101(13434)	TuTh	12:30pm	1:45pm	CSI 1115
1	CMSC102	0201(13435)	TuTh	2:00pm	3:15pm	CSI 1115
2	CMSC102	0301(13436)	TuTh	3:30pm	4:45pm	CSI 1115
3	CMSC114	0101(13446)	MWF	11:00am	11:50am	CSI 3117
4	CMSC114	0101(13446)	MW	4:00pm	4:50pm	CSI 2107
5	CMSC114	0102(13447)	MWF	11:00am	11:50am	CSI 3117
6	CMSC114	0102(13447)	MW	5:00pm	5:50pm	CSI 2107
7	CMSC114	0201(13448)	MWF	1:00pm	1:50pm	CSI 2117
8	CMSC114	0201(13448)	MW	4:00pm	4:50pm	CSI 2118
9	CMSC114	0203(13452)	MWF	1:00pm	1:50pm	CSI 2117
10	CMSC114	0203(13452)	MW	4:00pm	4:50pm	CSI 3120
11	CMSC114	0101(13461)	MWF	11:00am	11:50am	CSI 1115

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	Code	TitleCode	Days	TimeBegin	TimeEnd	Room
12	CMSC114	0101(13461)	MW	12:00pm	12:50pm	CSI 1121
13	CMSC114	0102(13462)	MWF	11:00am	11:50am	CSI 1115
14	CMSC114	0102(13462)	MW	1:00pm	1:50pm	CSI 1121
15	CMSC114	0103(13463)	MWF	11:00am	11:50am	CSI 1115
16	CMSC114	0103(13463)	MW	12:00pm	12:50pm	CSI 2107
17	CMSC114	0201(13464)	MWF	2:00pm	2:50pm	CSI 1115
18	CMSC114	0201(13464)	MW	12:00pm	12:50pm	CSI 2120
19	CMSC114	0301(13465)	MWF	2:00pm	2:50pm	CSI 1115
20	CMSC114	0301(13465)	MW	1:00pm	1:50pm	CSI 2120
21	CMSC114	0401(13466)	MWF	2:00pm	2:50pm	CSI 1115
22	CMSC114	0401(13466)	MW	1:00pm	1:50pm	CSI 2107
23	CMSC114	0101(13477)	MWF	10:00am	10:50am	CSI 2117
24	CMSC114	0101(13477)	MW	8:00am	8:50am	CSI 2107
25	CMSC114	0102(13478)	MWF	10:00am	10:50am	CSI 2117
26	CMSC114	0102(13478)	MW	9:00am	9:50am	CSI 2107
27	CMSC114	0201(13479)	MWF	11:00am	11:50am	CSI 2117
28	CMSC114	0201(13479)	MW	8:00am	8:50am	CSI 2120
29	CMSC114	0202(13480)	MWF	11:00am	11:50am	CSI 2117
30	CMSC114	0202(13480)	MW	9:00am	9:50am	CSI 2120
31	CMSC114	0301(13481)	MWF	12:00pm	12:50pm	CSI 2117
32	CMSC114	0301(13481)	MW	8:00am	8:50am	CSI 3120
33	CMSC114	0302(13482)	MWF	12:00pm	12:50pm	CSI 2117
34	CMSC114	0302(13482)	MW	9:00am	9:50am	CSI 3120
35	CMSC114	0101(13492)	TuTh	9:30am	10:45am	CSI 1115
36	CMSC114	0101(13492)	MW	10:00am	10:50am	CSI 1121
37	CMSC114	0102(13493)	TuTh	9:30am	10:45am	CSI 1115
38	CMSC114	0102(13493)	MW	11:00am	11:50am	CSI 1121
39	CMSC114	0201(13494)	TuTh	11:00am	12:15pm	CSI 1115
40	CMSC114	0201(13494)	MW	10:00am	10:50am	CSI 2107
41	CMSC114	0202(13495)	TuTh	11:00am	12:15pm	CSI 1115
42	CMSC114	0202(13495)	MW	11:00am	11:50am	CSI 2107
43	CMSC311	0101(13580)	TuTh	9:30am	10:45am	CSI 3117
44	CMSC311	0201(13581)	TuTh	11:00am	12:15pm	CSI 3117
45	CMSC330	0101(13591)	MW	10:00am	10:50am	CSI 3117
46	CMSC330	0101(13591)	MW	2:00pm	2:50pm	CSI 2107
47	CMSC330	0102(13592)	MW	10:00am	10:50am	CSI 3117
48	CMSC330	0102(13592)	MW	3:00pm	3:50pm	CSI 2107
49	CMSC330	0201(13593)	MW	12:00pm	12:50pm	CSI 1115
50	CMSC330	0201(13593)	MW	2:00pm	2:50pm	CSI 2120
51	CMSC330	0202(13594)	MW	12:00pm	12:50pm	CSI 1115
52	CMSC330	0202(13594)	MW	3:00pm	3:50pm	CSI 2120
53	CMSC330	0301(13595)	MW	1:00pm	1:50pm	CSI 1115
54	CMSC330	0301(13595)	MW	2:00pm	2:50pm	CSI 3120
55	CMSC330	0302(13596)	MW	1:00pm	1:50pm	CSI 1115
56	CMSC330	0302(13596)	MW	3:00pm	3:50pm	CSI 3120
57	CMSC330	0101(13606)	TuTh	3:30pm	4:45pm	CSI 1121
58	CMSC330	0201(13607)	MWF	2:00pm	2:50pm	CSI 3117
59	CMSC330	0301(13608)	MWF	3:00pm	3:50pm	CSI 3117
60	CMSC411	0101(13679)	TuTh	12:30pm	1:45pm	CSI 1121
61	CMSC411	0201(13680)	MW	3:30pm	4:45pm	CSI 1122

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	Code	TitleCode	Days	TimeBegin	TimeEnd	Room
62	CMSC412	0101(13690)	TuTh	12:30pm	1:45pm	CSI 1122
63	CMSC412	0101(13690)	MW	10:00am	10:50am	CSI 2120
64	CMSC412	0102(13691)	TuTh	12:30pm	1:45pm	CSI 1122
65	CMSC412	0102(13691)	MW	11:00am	11:50am	CSI 2120
66	CMSC412	0201(13692)	TuTh	9:30am	10:45am	CSI 1121
67	CMSC412	0201(13692)	MW	10:00am	10:50am	CSI 3120
68	CMSC412	0202(13693)	TuTh	9:30am	10:45am	CSI 1121
69	CMSC412	0202(13693)	MW	11:00am	11:50am	CSI 3120
70	CMSC412	0101(13703)	TuTh	12:30pm	1:45pm	CSI 2117
71	CMSC420	0101(13713)	TuTh	2:00pm	3:15pm	CSI 2117
72	CMSC420	0201(13714)	TuTh	3:30pm	4:45pm	CSI 2117
73	CMSC421	0101(13724)	TuTh	2:00pm	3:15pm	CSI 1122
74	CMSC424	0101(13734)	TuTh	11:00am	12:15pm	CSI 1121
75	CMSC424	0201(13735)	Tu	6:30pm	9:00pm	CSI 2117
76	CMSC426	0101(13744)	TuTh	11:00am	12:15pm	CSI 1122
77	CMSC427	0101(13754)	TuTh	2:00pm	3:15pm	CSI 3117
78	CMSC430	0101(13764)	TuTh	11:00am	12:15pm	CSI 2117
79	CMSC433	0101(13774)	TuTh	3:30pm	4:45pm	CSI 3117
80	CMSC434	0101(13784)	TuTh	9:30am	10:45am	CSI 1122
81	CMSC434	0201(13785)	MW	2:00pm	3:15pm	CSI 1122
82	CMSC435	0101(13795)	TuTh	2:00pm	3:15pm	CSI 1121
83	CMSC435	0201(13796)	TuTh	9:30am	10:45am	CSI 2107
84	CMSC435	0301(13797)	TuTh	11:00am	12:15pm	CSI 2120
85	CMSC450	0101(13806)	MWF	2:00pm	2:50pm	MTH 0405
86	CMSC451	0101(13816)	TuTh	12:30pm	1:45pm	CSI 3117
87	CMSC456	0101(13826)	MWF	10:00am	10:50am	MTH B0421
88	CMSC456	0201(13827)	MWF	1:00pm	1:50pm	MTH B0421
89	CMSC460	0101(13837)	MWF	9:00am	9:50am	MTH 0304
90	CMSC460	0201(13838)	TuTh	2:00pm	3:15pm	MTH 0101
91	CMSC466	0101(13848)	MWF	1:00pm	1:50pm	MTH 0403
92	CMSC475	0101(13858)	TuTh	9:30am	10:45am	MTH 0306
93	CMSC498A	0101(14750)	null_no_value	null_no_value	null_no_value	null_no_value
94	CMSC498W	0101(13929)	MW	2:00pm	3:15pm	CSI 1121
95	CMSC661	0101(14001)	TuTh	11:00am	12:15pm	CSI 3118
96	CMSC664	0101(14011)	TuTh	2:00pm	3:15pm	MTH 1308
97	CMSC666	0101(14021)	TuTh	9:30am	10:45am	MTH 0303
98	CMSC667	0101(14031)	TuTh	9:30am	10:45am	MTH 0307
99	CMSC711	0101(14041)	TuTh	2:00pm	3:15pm	CSI 2120
100	CMSC723	0101(14051)	W	4:00pm	6:30pm	CSI 3118
101	CMSC724	0101(14061)	TuTh	11:00am	12:15pm	CSI 2118
102	CMSC726	0101(14071)	TuTh	12:30pm	1:45pm	CSI 2120
103	CMSC733	0101(14737)	TuTh	12:30pm	1:45pm	CSI 3118
104	CMSC740	0101(14072)	TuTh	3:30pm	4:45pm	CSI 1122
105	CMSC751	0101(59774)	MW	11:00am	12:15pm	CSI 3118
106	CMSC818S	0101(14327)	TuTh	2:00pm	3:15pm	CSI 2107
107	CMSC828C	0101(59745)	TuTh	9:30am	10:45am	CSI 1122
108	CMSC828O	0101(59761)	M	5:30pm	8:15pm	EGR 3140
109	CMSC828R	0101(59764)	MW	11:00am	12:15pm	CSI 2118
110	CMSC838G	0101(14469)	TuTh	3:30pm	4:45pm	CSI 2107
111	CMSC838I	0101(14479)	M	4:00pm	4:50pm	CSI 2120

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	Code	TitleCode	Days	TimeBegin	TimeEnd	Room
112	CMSC838P	0101(14489)	TuTh	9:30am	10:45am	CSI 2120
113	CMSC838T	0101(14499)	TuTh	12:30pm	1:45pm	CSI 2107
114	CMSC838Z	0101(14509)	TuTh	3:30pm	4:45pm	CSI 2120
115	CMSC858A	0101(14591)	MWF	1:00pm	1:50pm	CSI 2118
116	CMSC858K	0101(14601)	TuTh	9:30am	10:45am	CSI 3120

Table 11: Brown University Courses (IConcept BrownUniCSCourse)

	Code	InstructorURL	Instructor	...
0	CS002	http://www.cs.brown.edu/~dls/	Stanford	...
1	CS004	http://www.cs.brown.edu/~ausas/	Usas	...
2	CS016	http://www.cs.brown.edu/~rt/	Tamassia	...
3	CS018	http://www.cs.brown.edu/~klein/	Klein	...
4	CS022	http://www.cs.brown.edu/~anna/	Lysyanskaya	...
5	CS032	http://www.cs.brown.edu/~spr/	Reiss	...
6	CS034	http://www.cs.brown.edu/~er/	Renieris	...
7	CS92	http://www.cs.brown.edu/~rbb/	Blumberg	...
8	CIT 506	null_no_value	null_no_value	...
9	CS138	http://www.cs.brown.edu/~ugur/	Cetintemel	...
10	CS141	http://www.cs.brown.edu/~amygreen/	Greenwald	...
11	CS148	http://www.cs.brown.edu/~ec/	Charniak	...
12	CS155	http://www.cs.brown.edu/~eli/	Upfal	...
13	CS168	http://www.cs.brown.edu/~twd/	Doeppner	...
14	CS181	http://www.cs.brown.edu/~franco/	Preparata	...
15	CS190	http://www.cs.brown.edu/~sk/	Krishnamurthi	...
16	CS196-9	http://www.cs.brown.edu/~dgd/	Durand	...

Table 11 – Continued

	CourseURL	Title	...
0	http://www.cs.brown.edu/courses/cs002/	Concepts Challenges of CS	...
1	http://www.cs.brown.edu/courses/cs004/	Intro to Scientific Computing	...
2	http://www.cs.brown.edu/courses/cs016/	Intro to Algorithms Data Structures	...
3	http://www.cs.brown.edu/courses/cs018/	CS: An Integrated Approach	...
4	http://www.cs.brown.edu/courses/cs022/	Intro. to Discrete Mathematics	...
5	http://www.cs.brown.edu/courses/cs032/	Intro. to Software Engineering	...
6	http://www.cs.brown.edu/courses/cs034/	Intro. to Systems Programming	...
7	null_no_value	Educational Software Seminar	...
8	null_no_value	null_no_value	...
9	http://www.cs.brown.edu/courses/cs138/	Networked Information Systems	...
10	http://www.cs.brown.edu/courses/cs141/	Intro. to Artificial Intelligence	...
11	http://www.cs.brown.edu/courses/cs148/	Building Intelligent Robots	...
12	http://www.cs.brown.edu/courses/cs155/	Probabilistic Methods in CS	...
13	http://www.cs.brown.edu/courses/cs168/	Computer Networks	...

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	CourseURL	Title	...
14	http://www.cs.brown.edu/courses/cs181/	Computational Molecular Biology	...
15	http://www.cs.brown.edu/courses/cs190/	Software System Design	...
16	http://www.cs.brown.edu/courses/cs196-9/	Document Engineering	...

Table 11 – Continued

	HoursType	Days	TimeBegin	TimeEnd	Room
0	C hr.	MWF	10am	11am	Salomon 001
1	K hr.	T,Th	2:30pm	4pm	MacMillan 117
2	D hr.	MWF	11am	12pm	CIT Lubrano
3	J hr.	T,Th	1pm	2:30pm	CIT 227
4	B hr.	MWF	9am	10am	CIT 165
5	K hr.	T,Th	2:30pm	4pm	CIT 165, Labs in Sunlab
6	null_no_value	THURSDAY ONLY	1pm	2:30pm	TBA
7	K hr.	T,Th	2:30pm	4pm	null_no_value
8	null_no_value	null_no_value	null_no_value	null_no_value	null_no_value
9	I hr.	T,Th	10:30am	12pm	CIT 368
10	I hr.	T,Th	10:30am	12pm	CIT 227
11	H hr.	T,Th	9am	10:30am	CIT 368
12	J hr.	T,Th	1pm	2:30pm	CIT 506
13	M hr.	M	3pm	5:30pm	CIT 368
14	K hr.	T,Th	2:30pm	4pm	CIT 368
15	D hr.	MWF	11am	12pm	CIT 368
16	H hr.	T,Th	9am	10:30am	CIT 506

Conflict Resolution: In SIRUP, composite values are required to be normalized before being offered through IConcepts. By this normalization, the original composite value for "Title" is split by creating the following attributes from it: "CourseURL", "Title", "HoursType", "Days", "TimeBegin", and "TimeEnd" (see Table 11). To find all courses with "Data Structures" in their title, we use the attribute transformation function matches to determine all courses whose title matches the given regular expression pattern (i.e., the character sequence "Data Structures"). This function is registered to SIRUP as follows:

Listing 4: Registering the Attribute Transformation Function matches with SIQL

```
0 create function matches
1 using class ch.uzh.ifi.sirup.siql.functions.attribute.Matches;
```

On these foundations, the desired results for benchmark query 3 can be determined with the following SIQL query:

Listing 5: SIQL Solution for THALIA Benchmark Query 3

```
0  select ∗ from (
1          (select c.Code, s.TitleCode, CourseName as Title, Instructor, Days,
2          TimeBegin, TimeEnd, Credits, GradeMethod, Seats, Open, Waitlist,
3          Room from (
4                  (       (select ∗ from UniMarylandCSCourse) as c
5                          inner join
6                          (select ∗ from UniMarylandCSCourseSection) as s
7                          on c.code = s.code)
8                  inner join
9                  (select ∗ from UniMarylandCSCourseSectionEvent) as e
10                 on e.code = c.code and s.titlecode = e.titlecode))
11         outer union
12         (select ∗ from BrownUniCSCourse) )
13 where matches(Title, "(.)∗Data Structures(.)∗") = true;
```

Result: The requested information on all courses with the string "Data Structures" in their title is shown in the following table (note the title information in the "Title" attribute):

Table 12: Result Data for SIQL Query from Listing 5

	Code	TitleCode	Title	Instructor	Days	...
0	CMSC420	0101(13713)	Data Structures	null_no_value	TuTh	...
1	CMSC420	0201(13714)	Data Structures	null_no_value	TuTh	...
2	CS016	null_no_attribute	Intro to Algorithms Data Structures	Tamassia	MWF	...

Table 12 – Continued

	TimeBegin	TimeEnd	Credits	GradeMethod	Seats	...
0	2:00pm	3:15pm	(3 credits)	REG.	null_no_value	...
1	3:30pm	4:45pm	(3 credits)	REG.	null_no_value	...
2	11am	12pm	null_no_attribute	null_no_attribute	null_no_attribute	...

Table 12 – Continued

	Open	Waitlist	Room	InstructorURL	...
0	null_no_value	null_no_value	CSI 2117	null_no_attribute	...
1	null_no_value	null_no_value	CSI 2117	null_no_attribute	...
2	null_no_attribute	null_no_attribute	CIT Lubrano	http://www.cs.brown.edu/∼rt/	...

Table 12 – Continued

	CourseURL	HoursType
0	null_no_attribute	null_no_attribute
1	null_no_attribute	null_no_attribute
2	http://www.cs.brown.edu/courses/cs016/	D hr.

5 Benchmark Query 4: Complex Mappings

Conflict: In this benchmark query, all database courses that carry more than ten credit hours have to be retrieved. The given course data for this query is from Carnegie Mellon University[7] and the Swiss Federal Institute of Technology Zürich (ETH)[8]. In addition to language conversion issues, the challenge here is to develop a mapping that coverts the numeric value for credit hours into a string that describes the expected scope (i.e., "Umfang") of the course.

Source Data: See Table 3 (IConcept CarnegieMellonCSCourse), Table 4 (IConcept CarnegieMellonCSLecturer), Table 13 (IConcept ETHZCSCourse), and Table 14 (IConcept ETHZCSLecturer).

Table 13: ETH Zurich Courses (IConcept ETHZCSCourse)

	Nummer	Titel	Semester	...
0	252-0001-00	Einführung in die Programmierung	1. Semester Bachelor-Studiengang	...
1	252-0002-00	Datenstrukturen Algorithmen	2. Semester Bachelor-Studiengang	...
2	252-0007-00	Logik	1. Semester Bachelor-Studiengang	...
3	252-0010-00	Diskrete Mathematik	2. Semester Bachelor-Studiengang	...
4	252-0014-00	Digitaltechnik	2. Semester Bachelor-Studiengang und 4. Semester	...
5	401-0131-00	Lineare Algebra	1. Semester Bachelor-Studiengang	...
6	401-0212-00	Analysis II	2. Semester Bachelor-Studiengang	...
7	401-0231-00	Analysis I	1. Semester Bachelor-Studiengang	...
8	401-0601-00	Wahrscheinlichkeit und Statistik	1. Semester Bachelor-Studiengang	...
9	402-0038-00	Physik	2. Semester Bachelor-Studiengang	...
10	251-0003-00	Informatik III	3. Semester	...
11	251-0004-00	Informatik IV	4. Semester	...

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[7] http://www.cs.cmu.edu/

[8] http://www.inf.ethz.ch

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	Nummer	Titel	Semester	...
12	251-0006-00	Theoretische Informatik-G	4. Semester	...
13	251-0008-00	Wissenschaftliches Rechnen	4. Semester	...
14	251-0016-00	Informationssysteme-G	4. Semester	...
15	251-0017-00	Information und Kommunikation	3. Semester	...
16	251-0019-00	Vernetzte Systeme	3. Semester	...
17	251-0021-00	Numerisches und symbolisches Rechnen	3. Semester	...
18	251-0023-00	Systemprogrammierung	3. Semester	...
19	252-0014-00	Digitaltechnik	2. Semester Bachelor-Studiengang und 4. Semester	...
20	227-0074-00	Elektrotechnik Praktikum	null_no_value	...
21	251-0102-00	Digitaltechnik und Rechnerstruktur	null_no_value	...
22	251-0201-00	System-Software	null_no_value	...
23	251-0301-00	Informationssysteme-K	null_no_value	...
24	251-0303-00	Verteilte Systeme	null_no_value	...
25	251-0402-00	Theoretische Informatik-K	null_no_value	...
26	251-0501-00	Wissenschaftliches Rechnen-K	null_no_value	...
27	251-0222-00	Compiler Design I	null_no_value	...
28	251-0223-00	Compiler Design II	null_no_value	...
29	251-0230-00	Stereoscopic Imaging	null_no_value	...
30	251-0233-00	C++ Templates and Generic Programming	null_no_value	...
31	251-0236-00	Planung und Leistungsanalyse skalierbarer E-Commerce und Client/Server Systeme im Internet	null_no_value	...
32	251-0237-00	Konzepte objektorientierter Programmierung	null_no_value	...
33	251-0238-00	Component-Oriented Virtual Machines with a Focus on .NET and Remoting	null_no_value	...
34	251-0239-00	Trusted components: principles, techniques, standards	null_no_value	...
35	251-0247-00	Formal Verification	null_no_value	...
36	251-0250-00	Object-oriented Software Construction	null_no_value	...
37	251-0261-00	Prinzipien des Concurrent Programming	null_no_value	...
38	251-0264-00	Semantik von Programmiersprachen	null_no_value	...
39	251-0268-00	Concurrent Object-Oriented Programming	null_no_value	...
40	251-0306-00	Parallel and Distributed Databases	null_no_value	...
41	251-0307-00	Enterprise Application Integration - Middleware	null_no_value	...
42	251-0312-00	Ubiquitous Computing	null_no_value	...
43	251-0317-00	XML und Datenbanken	null_no_value	...
44	251-0319-00	Verteilte Systeme	null_no_value	...
45	251-0332-00	Mobile Computing	null_no_value	...
46	251-0336-00	Principles of Distributed Computing	null_no_value	...
47	251-0342-00	Multimedia Retrieval	null_no_value	...
48	251-0343-00	Objektrelationale, erweiterbare Datenbanken	null_no_value	...
49	251-0350-00	Transaktionsverwaltung in modernen Informationssystemen	null_no_value	...
50	251-0355-00	Object-oriented Technologies for Data Management	null_no_value	...
51	251-0372-00	Global Information Systems	null_no_value	...
52	251-0407-00	Informationssicherheit und Kryptographie	null_no_value	...

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	Nummer	Titel	Semester	...
53	251-0408-00	Kryptographische Protokolle	null_no_value	...
54	251-0417-00	Randomisierte Algorithmen	null_no_value	...
55	251-0418-00	Algorithmische Geometrie	null_no_value	...
56	251-0423-00	Approximation: Theorie und Algorithmen	null_no_value	...
57	251-0425-00	Web Algorithms	null_no_value	...
58	251-0437-00	Verteilte Algorithmen	null_no_value	...
59	251-0449-00	Introduction to Quantum Computation	null_no_value	...
60	251-0460-00	Formal Methods for Information Security	null_no_value	...
61	251-0461-00	Information Security	null_no_value	...
62	251-0464-00	Pseudozufälligkeit und Derandomisierung	null_no_value	...
63	251-0480-00	Graphenalgorithmen	null_no_value	...
64	251-0482-00	Zufällige Graphen	null_no_value	...
65	251-0484-00	Abstract State Machines: Einführung in eine Entwurfs- und Analysemethode komplexer Systeme	null_no_value	...
66	251-0485-00	Graph Theory	null_no_value	...
67	251-0486-00	Managed Computation	null_no_value	...
68	251-0491-00	Erfüllbarkeit logischer Formeln - Kombinatorik und Algorithmen	null_no_value	...
69	251-0493-00	Algorithmen der Marktforschung	null_no_value	...
70	251-0495-00	Zufällige Graphen	null_no_value	...
71	251-0496-00	Komplexitätstheorie	null_no_value	...
72	251-0504-00	Numerische Methoden für grosse Matrixeigenwertprobleme	null_no_value	...
73	251-0523-00	Computational Biology	null_no_value	...
74	251-0526-00	Maschinen-Lernen II	null_no_value	...
75	251-0527-00	Bildverstehen mit statistischen Modellen	null_no_value	...
76	251-0531-00	Simulation of Complex Systems	null_no_value	...
77	251-0532-00	Bio-Inspired Computation Optimization	null_no_value	...
78	251-0535-00	Machine Learning I: Algorithms and Applications	null_no_value	...
79	251-0538-00	Surface Representations and Geometric Modeling	null_no_value	...
80	251-0543-00	Graphische Datenverarbeitung I	null_no_value	...
81	251-0544-00	Graphische Datenverarbeitung II	null_no_value	...
82	251-0545-00	Bild - Farbe - Reproduktion	null_no_value	...
83	251-0546-00	Physikalisch-basierte Simulation in der Computer Graphik	null_no_value	...
84	251-0548-00	Software for Numerical Linear Algebra	null_no_value	...
85	151-0314-00	Informationstechnologien im Digitalen Produkt	null_no_value	...
86	151-1121-0	CFD for Engineering Applications	null_no_value	...
87	227-0102-00	Diskrete Ereignissysteme	null_no_value	...
88	227-0116-00	VLSI I: von Architektur zu hochintegrierter Schaltung und FPGA	null_no_value	...
89	227-0120-00	Communication Networks	null_no_value	...
90	227-0124-00	Eingebettete Systeme	null_no_value	...
91	227-0147-00	VLSI II: Entwurf von hochintegrierten Schaltungen	null_no_value	...

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	Nummer	Titel	Semester	...
92	227-0148-00	VLSI III: Fabrikation und Verifikation hochintegrierter Schaltungen	null_no_value	...
93	227-0417-00	Applied Digital Information Theory I	null_no_value	...
94	227-0447-00	Bilddatenanalyse und Computer Vision I	null_no_value	...
95	227-0448-00	Bilddatenanalyse und Computer Vision II	null_no_value	...
96	227-0489-00	Algorithmen für Kommunikationsnetze	null_no_value	...
97	227-0577-00	Network Security	null_no_value	...
98	227-0587-00	Interprozesskommunikation in UNIX	null_no_value	...
99	227-0627-00	Computer System-Entwurf	null_no_value	...
100	227-0677-00	Sprachverarbeitung I	null_no_value	...
101	227-0678-00	Sprachverarbeitung II	null_no_value	...
102	227-0778-00	Hardware/Software Codesign	null_no_value	...
103	401-2694-00	Parallel Numerical Computing	null_no_value	...
104	401-3032-00	Einführung in die Mathematische Logik und Modelltheorie	null_no_value	...
105	401-3038-00	Rechnen mit reellen Zahlen und die Entscheidbarkeit der Elementaren Geometrie	null_no_value	...
106	401-3651-00	Numerik partieller Differentialgleichungen I (Rand- und Eigenwertprobleme)	null_no_value	...
107	401-3652-00	Numerik partieller Differentialgleichungen II (Anfangswertaufgaben)	null_no_value	...
108	401-3901-00	Optimierungstechniken	null_no_value	...
109	401-3902-00	Diskrete Optimierung	null_no_value	...
110	401-3904-00	Convex Optimization	null_no_value	...
111	402-0802-00	Informationsverarbeitung in neuronalen Netzwerken	null_no_value	...
112	251-0801-00	Informatik-Projektentwicklung	null_no_value	...
113	251-0803-00	Arbeitspsychologie	null_no_value	...
114	251-0808-00	Einführung in die Volkswirtschaftlehre (Mikro- und Makroökonomie)	null_no_value	...
115	351-0734-00	Arbeitsphysiologie	null_no_value	...
116	351-0790-00	Gründung, Aufbau und Führung neuer Unternehmen	null_no_value	...
117	851-0583-00	Einführung in die Soziologie I: Gegenstands- und Problembereiche moderner Gesellschaften	null_no_value	...
118	851-0703-00	Rechtslehre Grundzüge	null_no_value	...
119	851-0835-00	Scientific and Technical English / Fundamentals I	null_no_value	...
120	851-0836-00	Scientific Technical English - Fundamentals I	null_no_value	...
121	851-0837-00	Scientific and Technical English / Fundamentals II	null_no_value	...
122	851-0838-00	Scientific Technical English - Fundamentals II	null_no_value	...
123	251-0323-00	Projektführung und -abwicklung in der Praxis	null_no_value	...
124	251-0351-00	Informationsmanagement	null_no_value	...
125	251-0810-00	Distributed Systems Laboratory	null_no_value	...
126	251-0811-00	Applied Security Laboratory	null_no_value	...
127	251-0812-00	Sicherer Betrieb von Informatikmitteln in der Praxis	null_no_value	...
128	251-0817-00	Distributed Systems Laboratory	null_no_value	...

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	Nummer	Titel	Semester	...
129	251-0818-00	Problemlösen im Informatikalltag	null_no_value	...
130	251-0819-00	FATS Formal Approaches to Software	null_no_value	...
131	251-0820-00	Fallstudien aus der Praxis	null_no_value	...
132	251-0828-00	FATS Formal Approaches to Software	null_no_value	...
133	351-0777-00	Technologietransfer	null_no_value	...
134	351-0793-00	Praxis des Technologiemanagements	null_no_value	...
135	251-0207-00	Digitaltechnik und Rechnerarchitektur	null_no_value	...
136	251-0211-00	Spezifikation und Verifikation objektorientierter Software	null_no_value	...
137	251-0266-00	Referenzen und Aliasing in objektorientierten Programmen	null_no_value	...
138	251-0270-00	Concurrency Seminar	null_no_value	...
139	251-0310-00	Informations- und Kommunikationssysteme	null_no_value	...
140	251-0314-00	Verteilte Systeme	null_no_value	...
141	251-0339-00	Principles of Distributed Computing	null_no_value	...
142	251-0358-00	Informationssysteme in den Life Sciences	null_no_value	...
143	251-0422-00	Forschungsthemen der Kryptographie	null_no_value	...
144	251-0431-00	Seminar der Theoretischen Informatik	null_no_value	...
145	251-0432-00	Seminar der Theoretischen Informatik	null_no_value	...
146	251-0453-00	Multimediale und hochdimensionale Daten: Speicherung, Zugriff und Verarbeitung	null_no_value	...
147	251-0465-00	Highlights der Komplexitätstheorie	null_no_value	...
148	251-0488-00	Informatik und Logik	null_no_value	...
149	251-0490-00	Algorithmische Geometrie Computergraphik	null_no_value	...
150	251-0494-00	Extremal Combinatorics	null_no_value	...
151	251-0537-00	Computer Animation	null_no_value	...
152	251-0540-00	Computational Science	null_no_value	...
153	251-0551-00	Neuere Themen der Mustererkennung	null_no_value	...
154	227-0649-00	Internet Economics	null_no_value	...
155	251-0821-00	Informatik-Didaktik I	null_no_value	...
156	251-0822-00	Informatik-Didaktik II	null_no_value	...
157	251-0823-00	Unterrichtspraktikum	null_no_value	...
158	251-0824-00	Unterrichtspraktikum	null_no_value	...
159	251-0100-00	Kolloquium für Informatik	null_no_value	...
160	227-0930-00	Information Security / Informationssicherheit	null_no_value	...
161	251-0232-00	Software Design	null_no_value	...
162	251-0543-00	Graphische Datenverarbeitung I	null_no_value	...
163	251-0831-00	Informatik II (D-MAVT)	5. Semester	...
164	251-0832-00	Informatik (D-MAVT/2)	null_no_value	...
165	251-0834-00	Informationssysteme für Ingenieure (D-ITET, D-BEPR, D-FOWI)	null_no_value	...
166	251-0835-00	Informatik I (D-ITET)	null_no_value	...
167	251-0836-00	Informatik II (D-ITET/2)	null_no_value	...
168	251-0838-00	Informatik II (D-MAVT)	4. Sem.	...
169	251-0839-00	Einsatz von Informatikmitteln (D-UMNW, D-ERDW, D-AGRL)	null_no_value	...
170	251-0845-00	Informatik I (D-BAUG)	null_no_value	...
171	251-0846-00	Informatik II (D-BAUG/2)	null_no_value	...
172	251-0847-00	Informatik (D-MATH, D-PHYS)	null_no_value	...
173	251-0848-00	Informatik II (D-MATH/4)	null_no_value	...

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	Nummer	Titel	Semester	...
174	251-0849-00	Nachdiplomkurs “Räumliche Informationssysteme” (D-BAUG)	null_no_value	...
175	551-0432-00	Informatik für Biologie Pharmazie	null_no_value	...

Table 13 – Continued

	Homepage	Sprache	Umfang	UnterrichtTyp
0	http://se.inf.ethz.ch/teaching/ws2003/37-001/index.html	Deutsch	4V3U	Bachelorstudiengang
1	http://www.inf.ethz.ch/info2	Deutsch	4V2U	Bachelorstudiengang
2	http://www.inf.ethz.ch/∼staerk/teaching.html	Deutsch	2V1U	Bachelorstudiengang
3	null_no_value	Deutsch	4V2U	Bachelorstudiengang
4	http://www.fm.inf.ethz.ch/dt	Deutsch	3V2U	Bachelorstudiengang
5	null_no_value	Deutsch	4V2U	Bachelorstudiengang
6	null_no_value	Deutsch	2V1U	Bachelorstudiengang
7	null_no_value	Deutsch	I:4V2U II:5V3U	Bachelorstudiengang
8	null_no_value	Deutsch	3V1U	Bachelorstudiengang
9	http://people.web.psi.ch/vanderveen/indextop.html	Deutsch	3V2U	Bachelorstudiengang
10	null_no_value	Deutsch	3V1U	Diplomstudiengang
11	http://se.inf.ethz.ch/teaching/ss2004/0004/index.html	Englisch	3V2U	Diplomstudiengang
12	http://www.jn.inf.ethz.ch/ti/	Deutsch	3V2U	Diplomstudiengang
13	null_no_value	Deutsch	3V2U	Diplomstudiengang
14	http://www.globis.ethz.ch/education/is-g/	Englisch	3V2U	Diplomstudiengang
15	http://www.crypto.ethz.ch/teaching/	Deutsch	2V1U	Diplomstudiengang
16	http://www.distcomp.ethz.ch/courses.html	Deutsch	2V1U	Diplomstudiengang
17	null_no_value	Englisch	3V2U	Diplomstudiengang
18	http://www.iks.inf.ethz.ch/education/ws03/sysprog/	Englisch	3V3U	Diplomstudiengang
19	http://www.fm.inf.ethz.ch/dt	Deutsch	3V2U	Diplomstudiengang
20	null_no_value	Deutsch	1P	Diplomstudiengang
21	http://www.tik.ee.ethz.ch/tik/education/lectures/DRS/DRS.html	Deutsch	3V2U	Informatik Kern
22	http://www.cs.inf.ethz.ch/edu/37-201	Englisch	3V2U	Informatik Kern
23	http://www-dbs.ethz.ch/∼isk/	Deutsch	3V2U	Informatik Kern
24	http://www.inf.ethz.ch/vs/edu/WS0304/VS/index.html	Deutsch	3V2U	Informatik Kern
25	http://www.ti.inf.ethz.ch/ew/courses/TI04/index.html	Deutsch	3V2U	Informatik Kern
26	http://www.inf.ethz.ch/research/wr/education/kwr/	Englisch	3V2U	Informatik Kern

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	Homepage	Sprache	Umfang	UnterrichtTyp
27	http://www.cs.inf.ethz.ch/edu/37-222/index.html	Englisch	2V2U	Informatik Vertiefung
28	http://www.cs.inf.ethz.ch/edu/37-223/	Englisch	2V2U	Informatik Vertiefung
29	http://www.inf.ethz.ch/education/courses/www.lst.inf.ethz.ch/teaching	Englisch	2V1U1G	Informatik Vertiefung
30	http://www.inf.ethz.ch/∼zueff/teaching.htm	Englisch	2V1U	Informatik Vertiefung
31	null_no_value	Deutsch	2V1U	Informatik Vertiefung
32	null_no_value	Deutsch	2V1U	Informatik Vertiefung
33	http://www.cs.inf.ethz.ch/edu/37-238/	Englisch	2V1U	Informatik Vertiefung
34	null_no_value	Englisch	4G	Informatik Vertiefung
35	http://fm.inf.ethz.ch/fv	Englisch	2V1U	Informatik Vertiefung
36	null_no_value	Englisch	3G	Informatik Vertiefung
37	null_no_value	Deutsch	2V1U	Informatik Vertiefung
38	http://www.inf.ethz.ch/education/courses/Wird%20noch%20bekannt%20gegeben.	Deutsch	2V1U	Informatik Vertiefung
39	null_no_value	Englisch	2V1U	Informatik Vertiefung
40	http://www.iks.inf.ethz.ch/education/ss04/PDDBS	Englisch	2V1U	Informatik Vertiefung
41	http://www.inf.ethz.ch/department/IS/iks/education/	Englisch	2V2U	Informatik Vertiefung
42	http://www.inf.ethz.ch/vs/edu/SS2004/UC/index.html	Deutsch	2V	Informatik Vertiefung
43	http://www.dbs.ethz.ch/∼xml	Deutsch	2V1U	Informatik Vertiefung
44	http://www.inf.ethz.ch/vs/edu/WS0304/VS/index.html	Deutsch	3V2U	Informatik Vertiefung
45	http://distcomp.ethz.ch/courses.html	Deutsch	2V2U	Informatik Vertiefung
46	http://www.inf.ethz.ch/education/courses/www.distcomp.ethz.ch/courses.html	Englisch	2V1U	Informatik Vertiefung
47	null_no_value	Deutsch	2V1U	Informatik Vertiefung
48	http://www.dbs.ethz.ch/∼ordb	Deutsch	2V1U	Informatik Vertiefung
49	http://www.dbs.ethz.ch/∼timi/	Deutsch	2V1U	Informatik Vertiefung
50	null_no_value	Englisch	2V1U	Informatik Vertiefung
51	null_no_value	Englisch	2V1U	Informatik Vertiefung
52	http://www.crypto.ethz.ch/ teaching/	Deutsch	2V2U	Informatik Vertiefung
53	http://www.crypto.ethz.ch/ teaching/	Deutsch	2V2U	Informatik Vertiefung
54	null_no_value	Deutsch	2V1U	Informatik Vertiefung
55	http://www.ti.inf.ethz.ch/ew/courses/CG04/	Deutsch	2V1U	Informatik Vertiefung
56	http://www.ti.inf.ethz.ch/ew/courses/ApproxAlgs0304/	Deutsch	2V1U	Informatik Vertiefung

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	Homepage	Sprache	Umfang	UnterrichtTyp
57	http://www.ti.inf.ethz.ch/pw/teaching/webalgs	Englisch	2V1U	Informatik Vertiefung
58	http://www.inf.ethz.ch/vs/edu/WS0304/VA/index.html	Deutsch	3G	Informatik Vertiefung
59	null_no_value	Englisch	2V1U	Informatik Vertiefung
60	null_no_value	Englisch	2V2U	Informatik Vertiefung
61	http://www.infsec.ethz.ch/education/ws0304/infsec	Englisch	2V2U	Informatik Vertiefung
62	null_no_value	Deutsch	2V1U	Informatik Vertiefung
63	null_no_value	Deutsch	2V1U	Informatik Vertiefung
64	null_no_value	Deutsch	2V1U	Informatik Vertiefung
65	http://www.inf.ethz.ch/∼staerk/teaching.html	Deutsch	2V1U	Informatik Vertiefung
66	http://www.ti.inf.ethz.ch/ew/courses/GT03/	Englisch	2V1U	Informatik Vertiefung
67	http://www.inf.ethz.ch/∼staerk/teaching.html	Deutsch	2V1U	Informatik Vertiefung
68	http://www.ti.inf.ethz.ch/ew/courses/SAT03/index.html	Deutsch	2V1U	Informatik Vertiefung
69	http://www.inf.ethz.ch/personal/giesen/tch/COMAlec_WS04/lec.html	Deutsch	2V1U	Informatik Vertiefung
70	null_no_value	Deutsch	2V1U	Informatik Vertiefung
71	null_no_value	Deutsch	2V1U	Informatik Vertiefung
72	http://www.inf.ethz.ch/research/wr/education/ewp/	Deutsch	3G	Informatik Vertiefung
73	http://www.inf.ethz.ch/research/wr/education/cb/	Englisch	2V1U	Informatik Vertiefung
74	http://www.vision.ethz.ch/ml	Deutsch	2V1U	Informatik Vertiefung
75	null_no_value	Deutsch	2V1U	Informatik Vertiefung
76	http://sim.inf.ethz.ch/teach/cosy	Englisch	3G	Informatik Vertiefung
77	http://www.icos.ethz.ch/teaching/bco03_dat.html	Englisch	2V1U	Informatik Vertiefung
78	http://www.inf.ethz.ch/education/courses/www.icos.ethz.ch	Englisch	2V1U	Informatik Vertiefung
79	http://graphics.ethz.ch/	Englisch	2V1U	Informatik Vertiefung
80	http://graphics.ethz.ch/	Deutsch	2V1U	Informatik Vertiefung
81	http://graphics.ethz.ch/gdv2	Deutsch	2V1U	Informatik Vertiefung
82	null_no_value	Deutsch	2V1U	Informatik Vertiefung
83	null_no_value	Deutsch	2V1U	Informatik Vertiefung
84	null_no_value	Deutsch	2V2U	Informatik Vertiefung
85	null_no_value	Deutsch	3G	Informatik Vertiefung
86	http://www.inf.ethz.ch/education/courses/www.icos.ethz.ch	Englisch	2V1U	Informatik Vertiefung
87	null_no_value	Deutsch	4G	Informatik Vertiefung
88	http://www.iis.ee.ethz.ch/stud_area/vorlesungen/vlsi1.en.html	Deutsch	5G	Informatik Vertiefung
89	null_no_value	Englisch	4G	Informatik Vertiefung
90	null_no_value	Deutsch	4G	Informatik Vertiefung

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	Homepage	Sprache	Umfang	UnterrichtTyp
91	http://www.iis.ee.ethz.ch/ stud_area/Vorlesungen/ vlsi2.en.html	Deutsch	5G (2V1U2P)	Informatik Vertiefung
92	http://www.iis.ee.ethz.ch/ stud_area/Vorlesungen/ vlsi3.en.html	Deutsch	4G(2V2U)	Informatik Vertiefung
93	null_no_value	Englisch	4G(2V2U)	Informatik Vertiefung
94	null_no_value	Englisch	4G(2V2U)	Informatik Vertiefung
95	null_no_value	Englisch	4G(2V2U)	Informatik Vertiefung
96	http://www.tik.ee.ethz.ch/tik/education/lectures/AFK/ WS03_04/	Deutsch	2V2U	Informatik Vertiefung
97	null_no_value	Deutsch	2V1U1P	Informatik Vertiefung
98	http://www.tik.ee.ethz.ch/tik/education/lectures/IPK/	Deutsch	2V2U	Informatik Vertiefung
99	null_no_value	Deutsch	4G	Informatik Vertiefung
100	http://www.tik.ee.ethz.ch/ ∼pfister/SPV-Info.html	Deutsch	4G (2V2U)	Informatik Vertiefung
101	http://www.tik.ee.ethz.ch/ ∼pfister/SPV-Info.html	Deutsch	4G (2V2U)	Informatik Vertiefung
102	null_no_value	Deutsch	2V2U	Informatik Vertiefung
103	null_no_value	Englisch	2V2U	Informatik Vertiefung
104	null_no_value	Deutsch	2V	Informatik Vertiefung
105	null_no_value	Deutsch	2V	Informatik Vertiefung
106	http://www.sam.math.ethz.ch/ Courses/index.html	Deutsch	3V1U	Informatik Vertiefung
107	http://www.sam.math.ethz.ch/ Courses/index.html	Deutsch	3V1U	Informatik Vertiefung
108	http://www.inf.ethz.ch/education/ courses/www.ifor.math.ethz.ch	Deutsch	2V1U	Informatik Vertiefung
109	null_no_value	Deutsch	2V1U	Informatik Vertiefung
110	http://www.ifor.math.ethz.ch/	Englisch	2V1U	Informatik Vertiefung
111	null_no_value	Deutsch	2V1U	Informatik Vertiefung
112	null_no_value	Deutsch	2G	Ergänzung
113	null_no_value	Deutsch	2G	Ergänzung
114	http://www.vwl.ethz.ch/	Deutsch	2V	Ergänzung
115	null_no_value	Deutsch	2G	Ergänzung
116	null_no_value	Deutsch	2V	Ergänzung
117	http://www.socio.ethz.ch/de/ teaching.html	Deutsch	1V1K	Ergänzung
118	null_no_value	Deutsch	2V	Ergänzung
119	null_no_value	Englisch	2V	Ergänzung
120	null_no_value	Englisch	2V	Ergänzung
121	null_no_value	Englisch	2V	Ergänzung
122	null_no_value	Englisch	2V	Ergänzung
123	null_no_value	Deutsch	2V	Anwendung
124	http://www-ea.inf.ethz.ch/lv/im/ index.html	Deutsch	2V	Anwendung
125	http://www.inf.ethz.ch/vs/edu/ lab.html	Englisch	8U	Anwendung

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	Homepage	Sprache	Umfang	UnterrichtTyp
126	http://www.infsec.ethz.ch/lab/appliedlab/	Englisch	3G	Anwendung
127	http://www-ea.inf.ethz.ch/lv/sibim04	Deutsch	2G	Anwendung
128	http://www.inf.ethz.ch/vs/edu/lab.html	Englisch	8U	Anwendung
129	http://www.ifi.unizh.ch/ddis/pia04.0.html	Deutsch	2V	Anwendung
130	null_no_value	Englisch	1V	Anwendung
131	http://www.inf.ethz.ch/~bohn/fallstudien/	Deutsch	3G	Anwendung
132	null_no_value	Englisch	1V	Anwendung
133	null_no_value	Deutsch	1V	Anwendung
134	null_no_value	Deutsch	1V	Anwendung
135	http://fm.inf.ethz.ch/dt-sem	Englisch	2S	Fachseminar
136	null_no_value	Deutsch	2S	Fachseminar
137	http://www.inf.ethz.ch/education/courses/Wird%20noch%20bekannt%20gegeben.	Englisch	2S	Fachseminar
138	null_no_value	Englisch	1S	Fachseminar
139	http://www.ccic.ethz.ch/	Deutsch	2S	Fachseminar
140	http://www.inf.ethz.ch/vs/edu/SS2004/DS/index.html	Deutsch	2S	Fachseminar
141	http://www.inf.ethz.ch/education/courses/www.distcomp.ethz.ch/courses.hrml	Englisch	2S	Fachseminar
142	http://www.fgcz.ethz.ch/isls/	Deutsch	2S	Fachseminar
143	http://www.crypto.ethz.ch/teaching/	Englisch	2S	Fachseminar
144	http://www.ti.inf.ethz.ch/ew/mise/mittagssem.html	Deutsch	2S	Fachseminar
145	http://www.ti.inf.ethz.ch/ew/mise/mittagssem.html	Deutsch	2S	Fachseminar
146	null_no_value	Deutsch	2S	Fachseminar
147	null_no_value	Deutsch	2S	Fachseminar
148	http://www.inf.ethz.ch/~staerk/teaching.html	Deutsch	2S	Fachseminar
149	http://www.inf.ethz.ch/personal/giesen/tch/AGCGsem_SS04/sem.html	Deutsch	2S	Fachseminar
150	null_no_value	Englisch	2S	Fachseminar
151	http://graphics.ethz.ch/seminar/	Deutsch	2S	Fachseminar
152	http://www.icos.ethz.ch/education/courses/courses/computational_science	Englisch	2S	Fachseminar
153	http://www.inf.ethz.ch/~hsteck/lehre/sem03_belief_prop/	Deutsch	2S	Fachseminar
154	null_no_value	Deutsch	2S	Fachseminar
155	http://www.tedu.ethz.ch/didaktik/	Deutsch	3G	Didaktik in der Informatik
156	http://www.tedu.ethz.ch/didaktik/	Deutsch	3G(2V1U)	Didaktik in der Informatik

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	Homepage	Sprache	Umfang	UnterrichtTyp
157	null_no_value	Deutsch	P	Didaktik in der Informatik
158	null_no_value	Deutsch	P	Didaktik in der Informatik
159	null_no_value	Deutsch	2K	Allgemein zugängliche Veranstaltungen
160	http://www.zisc.ethz.ch/events/istalksss2003.html	Deutsch	1K	Allgemein zugängliche Veranstaltungen
161	http://www.cs.fh-aargau.ch/~gruntz/courses/eth_sd/	Deutsch	2V1U	Informatik für Nichtinformatiker
162	http://graphics.ethz.ch/	Deutsch	2V1U	Informatik für Nichtinformatiker
163	null_no_value	Deutsch	4G	Informatik für Nichtinformatiker
164	http://www.info1-mavt.inf.ethz.ch/	Deutsch	2V2U	Informatik für Nichtinformatiker
165	null_no_value	Deutsch	2V1U	Informatik für Nichtinformatiker
166	http://graphics.ethz.ch/	Deutsch	2V2U	Informatik für Nichtinformatiker
167	http://www.inf.ethz.ch/vs/edu/SS2004/I2/index.html	Deutsch	2V1U	Informatik für Nichtinformatiker
168	null_no_value	Deutsch	2V1U	Informatik für Nichtinformatiker
169	http://www.evim.ethz.ch/	Deutsch	2G	Informatik für Nichtinformatiker
170	null_no_value	Deutsch	2V2U	Informatik für Nichtinformatiker
171	http://www.inf.ethz.ch/~pvrohr/Courses/InformatikII/	Deutsch	3G	Informatik für Nichtinformatiker
172	http://graphics.ethz.ch/37-847/	Deutsch	2V2U	Informatik für Nichtinformatiker
173	http://www.inf.ethz.ch/personal/giesen/INF2lec_SS04.html	Deutsch	2V1U	Informatik für Nichtinformatiker
174	null_no_value	Deutsch	200 Stunden	Informatik für Nichtinformatiker
175	http://www.evim.ethz.ch/	Deutsch	2V2U	Informatik für Nichtinformatiker

Table 14: ETH Zurich Lecturers (IConcept ETHZCSLecturer)

	Nummer	Nachname
0	252-0001-00	Meyer
1	252-0002-00	Widmayer
2	252-0007-00	Stärk
3	252-0010-00	Maurer
4	252-0014-00	Biere
5	401-0131-00	Gutknecht
6	401-0131-00	Gander

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	Nummer	Nachname
7	401-0212-00	Ilmanen
8	401-0231-00	Mislin
9	401-0231-00	Trubowitz
10	401-0601-00	Schweizer
11	402-0038-00	Van der Veen
12	251-0003-00	Stärk
13	251-0003-00	Basin
14	251-0004-00	Meyer
15	251-0006-00	Nievergelt
16	251-0006-00	Basin
17	251-0008-00	Gander
18	251-0016-00	Norrie
19	251-0017-00	Maurer
20	251-0019-00	Wattenhofer
21	251-0021-00	Koumoutsakos
22	251-0023-00	Gross
23	251-0023-00	Alonso
24	251-0023-00	Rauch
25	252-0014-00	Biere
26	227-0074-00	Vahldieck
27	251-0102-00	Thiele
28	251-0201-00	Gross
29	251-0201-00	Alonso
30	251-0201-00	Reali
31	251-0301-00	Norrie
32	251-0301-00	Schek
33	251-0303-00	Mattern
34	251-0303-00	Alonso
35	251-0402-00	Welzl
36	251-0402-00	Matousek
37	251-0501-00	Buhmann
38	251-0222-00	Gross
39	251-0223-00	Gross
40	251-0230-00	Kornfeld
41	251-0230-00	Gross
42	251-0233-00	Zueff
43	251-0236-00	Reiser
44	251-0237-00	Müller
45	251-0238-00	Gutknecht
46	251-0238-00	Zueff
47	251-0239-00	Meyer
48	251-0247-00	Biere
49	251-0250-00	Meyer
50	251-0261-00	Gutknecht
51	251-0264-00	Müller
52	251-0268-00	Meyer
53	251-0268-00	Bailly
54	251-0306-00	Alonso
55	251-0307-00	Alonso
56	251-0312-00	Mattern

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	Nummer	Nachname
57	251-0317-00	Türker
58	251-0319-00	Mattern
59	251-0319-00	Alonso
60	251-0332-00	Wattenhofer
61	251-0336-00	Wattenhofer
62	251-0342-00	Weber
63	251-0343-00	Türker
64	251-0350-00	Schek
65	251-0355-00	Norrie
66	251-0372-00	Norrie
67	251-0407-00	Maurer
68	251-0408-00	Maurer
69	251-0408-00	Hirt
70	251-0417-00	Steger
71	251-0418-00	Gärtner
72	251-0418-00	Jacob
73	251-0423-00	Widmayer
74	251-0423-00	Gärtner
75	251-0423-00	Cochand
76	251-0423-00	Steger
77	251-0425-00	Widmayer
78	251-0425-00	Jacob
79	251-0437-00	Mattern
80	251-0449-00	Poritz
81	251-0460-00	Vigano
82	251-0460-00	Mantel
83	251-0461-00	Basin
84	251-0464-00	Bläser
85	251-0480-00	Steger
86	251-0482-00	Gerke
87	251-0484-00	Stärk
88	251-0485-00	Szabo
89	251-0486-00	Stärk
90	251-0491-00	Welzl
91	251-0493-00	Giesen
92	251-0495-00	Steger
93	251-0496-00	Hromkovic
94	251-0504-00	Arbenz
95	251-0523-00	Cannarozzi-Bossard
96	251-0523-00	von Rohr
97	251-0526-00	Buhmann
98	251-0527-00	Buhmann
99	251-0527-00	Roth
100	251-0531-00	Nagel
101	251-0532-00	Zitzler
102	251-0532-00	Hansen
103	251-0535-00	Buhmann
104	251-0538-00	Gross
105	251-0543-00	Gross
106	251-0544-00	Gross

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	Nummer	Nachname
107	251-0544-00	Peikert
108	251-0545-00	Simon
109	251-0546-00	Teschner
110	251-0546-00	Müller
111	251-0548-00	Gutknecht
112	251-0548-00	Gander
113	251-0548-00	Parlett
114	151-0314-00	Meier
115	151-0314-00	Montau
116	151-0314-00	Zwicker
117	151-1121-0	Koumoutsakos
118	151-1121-0	Walther
119	151-1121-0	Stolz
120	227-0102-00	Thiele
121	227-0116-00	Fichtner
122	227-0116-00	Felber
123	227-0116-00	Kaeslin
124	227-0120-00	Plattner
125	227-0124-00	Thiele
126	227-0147-00	Fichtner
127	227-0147-00	Felber
128	227-0147-00	Kaeslin
129	227-0148-00	Fichtner
130	227-0148-00	Felber
131	227-0148-00	Kaeslin
132	227-0417-00	Lapidoth
133	227-0447-00	Székely
134	227-0447-00	van Gool
135	227-0448-00	Van Gool
136	227-0448-00	Székely
137	227-0489-00	Erlebach
138	227-0577-00	Plattner
139	227-0577-00	Caronni
140	227-0577-00	Weiler
141	227-0587-00	Lubich
142	227-0627-00	Gunzinger
143	227-0677-00	Pfister
144	227-0677-00	Hutter
145	227-0678-00	Pfister
146	227-0678-00	Hutter
147	227-0678-00	Traber
148	227-0778-00	Platzner
149	401-2694-00	Petersen
150	401-3032-00	Makowsky
151	401-3038-00	Makowsky
152	401-3651-00	Prohl
153	401-3652-00	Torrilhon
154	401-3901-00	Lüthi
155	401-3902-00	Cochand
156	401-3904-00	Lüthi

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	Nummer	Nachname
157	401-3904-00	Parillo
158	402-0802-00	Bernasconi
159	251-0801-00	Müller
160	251-0803-00	Wehner
161	251-0808-00	Schips
162	351-0734-00	Krueger
163	351-0790-00	Lattmann
164	351-0790-00	Fahrni
165	851-0583-00	Buchmann
166	851-0703-00	Ruch
167	851-0703-00	Nef
168	851-0835-00	Guess
169	851-0836-00	Guess
170	851-0837-00	Guess
171	851-0838-00	Guess
172	251-0323-00	Weydert
173	251-0351-00	Schucan
174	251-0810-00	Mattern
175	251-0810-00	Alonso
176	251-0810-00	Wattenhofer
177	251-0811-00	Basin
178	251-0811-00	Naef
179	251-0812-00	Aebi
180	251-0817-00	Mattern
181	251-0817-00	Alonso
182	251-0817-00	Wattenhofer
183	251-0818-00	Schucan
184	251-0818-00	Mresse
185	251-0818-00	Bernstein
186	251-0819-00	Müller
187	251-0819-00	Stärk
188	251-0819-00	Biere
189	251-0819-00	Meyer
190	251-0820-00	Gutknecht
191	251-0820-00	Brandis
192	251-0828-00	Stärk
193	251-0828-00	Biere
194	251-0828-00	Meyer
195	251-0828-00	Müller
196	351-0777-00	von Waldkirch
197	351-0793-00	Bodmer
198	251-0207-00	Biere
199	251-0211-00	Biere
200	251-0211-00	Müller
201	251-0266-00	Biere
202	251-0266-00	Müller
203	251-0270-00	Meyer
204	251-0270-00	Bailly
205	251-0310-00	Alonso
206	251-0314-00	Mattern

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	Nummer	Nachname
207	251-0339-00	Wattenhofer
208	251-0358-00	Schek
209	251-0358-00	Stolte
210	251-0422-00	Nielsen
211	251-0431-00	Welzl
212	251-0431-00	Gärtner
213	251-0431-00	Szabo
214	251-0431-00	Giesen
215	251-0432-00	Welzl
216	251-0432-00	Gärtner
217	251-0432-00	Szabo
218	251-0432-00	Giesen
219	251-0453-00	Widmayer
220	251-0465-00	Bläser
221	251-0488-00	Stärk
222	251-0490-00	Welzl
223	251-0490-00	Gross
224	251-0490-00	Giesen
225	251-0494-00	Szabo
226	251-0537-00	Teschner
227	251-0537-00	Müller
228	251-0540-00	Gonnet
229	251-0540-00	Gander
230	251-0540-00	Arbenz
231	251-0540-00	Koumoutsakos
232	251-0540-00	Buhmann
233	251-0551-00	Roth
234	251-0551-00	Buhmann
235	227-0649-00	Stiller
236	251-0821-00	Hromkovic
237	251-0822-00	Hartmann
238	251-0823-00	Hartmann
239	251-0824-00	Hartmann
240	251-0100-00	Professoren für Informatik
241	227-0930-00	Maurer
242	227-0930-00	Plattner
243	227-0930-00	Basin
244	251-0232-00	Gruntz
245	251-0543-00	Gross
246	251-0831-00	Schiele
247	251-0831-00	Koumoutsakos
248	251-0832-00	Bläser
249	251-0834-00	Marti
250	251-0835-00	Giesen
251	251-0836-00	Mattern
252	251-0838-00	Arbenz
253	251-0838-00	Bauer-Messmer
254	251-0838-00	Koumoutsakos
255	251-0839-00	Hinterberger
256	251-0845-00	Arbenz

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	Nummer	Nachname
257	251-0846-00	von Rohr
258	251-0847-00	Gärtner
259	251-0848-00	Giesen
260	251-0849-00	Zehnder
261	251-0849-00	Grün
262	251-0849-00	et. al.
263	251-0849-00	Türker
264	551-0432-00	Hinterberger

Conflict Resolution: At Carnegie Mellon University, one unit represents one work-hour of time per week throughout the semester for an average student.[9] According to their online course catalog,[10] the semester at Carnegie Mellon University is comprised of about 14 weeks (i.e., full weeks of lectures, without public holidays). Thus, one unit can be regarded as the equivalent of about 14 hours of work. At ETH Zurich, on the other hand, the amount of work needed for a course is represented in credit points according to the European Credit Transfer System (ETCS)[11]. Here, one credit point is the equivalent of about 25 to 30 hours of work. In our case, we assume 30 hours of work for one ECTS credit point.

Based on the amount of assumed working hours, the following formula can be employed for the necessary credit unit conversions:

$$\frac{ETCS(Umfang) \times 30}{14} = Units \tag{1}$$

where $ETCS$ is a function that converts the representation for "Umfang" as used by ETH Zurich into credit points according to ETCS, and $Units$ are credit units according to the Carnegie Mellon University. Because there is no general rule that can be applied to precisely derive the ETCS points for all ETH courses of the given THALIA data set, we employ an approximation for the $ETCS$ function that is sufficient for our demonstration case.[12] For use in SIQL, we implemented an attribute transformation function class called ETH2CMU to realize the conversion from Equation 1; then, it can be registered to SIRUP with the following declaration:

Listing 6: Registering the Attribute Transformation Function eth2cmu with SIQL

```
0 create function eth2cmu
1 using class ch.uzh.ifi.sirup.siql.functions.attribute.ETH2CMU;
```

In addition, we employ a function to achieve the necessary language translations from German to English based on [Alt07]:

Listing 7: Registering the Attribute Transformation Function ger2eng with SIQL

```
0 create function ger2eng
1 using class ch.uzh.ifi.sirup.siql.functions.attribute.Ger2Eng;
```

[9] See http://www.cmu.edu/hub/reg/grading_policies.html

[10] See http://www.cmu.edu/esg-cat/

[11] http://ec.europa.eu./education/programmes/socrates/ects/index_en.html

[12] This approximation is based on the contact hours only; however, also the time needed for course preparations, exercise homework, additional reading, etc. should be considered.

On these foundation, the challenge from benchmark query 4 can be mastered with the following SIQL query:

Listing 8: SIQL Solution for THALIA Benchmark Query 4

```
0  select ∗ from (
1          (select c.Code, c.Sec, CourseTitle, Lecturer, Room, Day,
2          TimeBegin, TimeEnd, Units, CourseX−Listed from
3                  (select ∗ from CarnegieMellonCSCourse) as c
4                  inner join
5                  (select ∗ from CarnegieMellonCSLecturer) as l
6                  on c.Code = l.Code and l.Sec = c.Sec)
7          outer union
8          (select c.Nummer as Code, Titel as CourseTitle,
9          Nachname as Lecturer, Semester, Homepage, Sprache,
10         Umfang, eth2cmu(Umfang) as Units, UnterrichtTyp from
11                 (select ∗ from ETHZCSCourse) as c
12                 inner join
13                 (select ∗ from ETHZCSLecturer) as l
14                 on c.Nummer = l.Nummer) )
15 where Units > 10 and
16         matches(ger2eng(CourseTitle), ”(.)∗Database(.)∗”) = true;
```

Result: Based on the query from Listing 8, the requested information on all database courses that carry more than ten credit hours is shown in the following table (note the credit information in attribute “Units”):

Table 15: Result Data for SIQL Query from Listing 8

	Code	Sec	CourseTitle	Lecturer	...
0	15-721*	A	Database System Design and Implementation	Ailamaki	...
1	251-0306-00	null_no_attribute	Parallel and Distributed Databases	Alonso	...
2	251-0317-00	null_no_attribute	XML und Datenbanken	Türker	...
3	251-0343-00	null_no_attribute	Objektrelationale, erweiterbare Datenbanken	Türker	...

Table 15 – Continued

	Room	Day	TimeBegin	TimeEnd	Units	...
0	WeH 4615A	MWF	1:30pm	2:50pm	12	...
1	null_no_attribute	null_no_attribute	null_no_attribute	null_no_attribute	11	...
2	null_no_attribute	null_no_attribute	null_no_attribute	null_no_attribute	11	...
3	null_no_attribute	null_no_attribute	null_no_attribute	null_no_attribute	11	...

Table 15 – Continued

	CourseX-Listed	Semester	Homepage	Sprache	...
0	.	null_no_attribute	null_no_attribute	null_no_attribute	...
1	null_no_attribute	null_no_value	http://www.iks.inf.ethz.ch/education/ss04/PDDBS	Englisch	...
2	null_no_attribute	null_no_value	http://www.dbs.ethz.ch/~xml	Deutsch	...
3	null_no_attribute	null_no_value	http://www.dbs.ethz.ch/~ordb	Deutsch	...

Table 15 – Continued

	Umfang	UnterrichtTyp
0	null_no_attribute	null_no_attribute
1	2V1U	Informatik Vertiefung
2	2V1U	Informatik Vertiefung
3	2V1U	Informatik Vertiefung

6 Benchmark Query 5: Language Expression

Conflict: In the fifth THALIA query, all courses with the string "database" in the course title are requested; thereby, also courses in other languages than English should be found — e.g., courses whose German title contains "Datenbank". The given course data for this query is from University of Maryland and the Swiss Federal Institute of Technology Zürich (ETH). The challenge for the data integration system here is to convert the German course titles into their English counterparts to compare the corresponding course names.

Source Data: See Table 8 (IConcept UniMarylandCSCourse), Table 9 (IConcept UniMaryland-CSCourseSection), Table 10 (IConcept UniMarylandCSCourseSectionEvent), Table 13 (IConcept ETHZCSCourse), and Table 14 (IConcept ETHZCSLecturer).

Conflict Resolution: By reuse of the attribute transformation functions matches (see Listing 4) and ger2eng (see Listing 7), the challenge for benchmark query 5 can be addressed with the following SIQL query:

Listing 9: SIQL Solution for THALIA Benchmark Query 5

```
0  select ∗ from (
1          (select c.Code, s.TitleCode, CourseName, Instructor,
2          Credits, GradeMethod, Seats, Open, Waitlist, Days,
3          TimeBegin, TimeEnd, Room from (
4          (                    (select ∗ from UniMarylandCSCourse) as c
5                               inner join
6                               (select ∗ from UniMarylandCSCourseSection) as s
7                               on c.code = s.code )
8                    inner join
9                    (select ∗ from UniMarylandCSCourseSectionEvent) as e
10                   on e.code = c.code and s.titlecode = e.titlecode))
11         outer union
12         (select c.Nummer as Code, Titel as CourseName,
13         Semester, Homepage, Sprache, Umfang, UnterrichtTyp,
14         Nachname as Instructor from (
15                   (select ∗ from ETHZCSCourse) as c
16                   inner join
17                   (select ∗ from ETHZCSLecturer) as l
18                   on c.Nummer = l.Nummer)) )
19 where matches(ger2eng(CourseName), "(.)∗Database(.)∗") = true;
```

Result: The requested information on all courses with the string "database" in the course title is shown in the following table (note the title information in attribute "CourseName"):

Table 16: Result Data for SIQL Query from Listing 9

	Code	TitleCode	CourseName	Instructor	...
0	CMSC424	0101(13734)	Database Design	null_no_value	...
1	CMSC424	0201(13735)	Database Design	Shapiro	...
2	CMSC724	0101(14061)	Database Management Systems	null_no_value	...
3	251-0306-00	null_no_attribute	Parallel and Distributed Databases	Alonso	...
4	251-0317-00	null_no_attribute	XML und Datenbanken	Türker	...
5	251-0343-00	null_no_attribute	Objektrelationale, erweiterbare Datenbanken	Türker	...

Table 16 – Continued

	Credits	GradeMethod	Seats	Open	...
0	(3 credits)	REG. CORE Capstone (CS) Course.	null_no_value	null_no_value	...
1	(3 credits)	REG. CORE Capstone (CS) Course.	50	6	...
2	(3 credits)	REG/AUD.	null_no_value	null_no_value	...
3	null_no_attribute	null_no_attribute	null_no_attribute	null_no_attribute	...
4	null_no_attribute	null_no_attribute	null_no_attribute	null_no_attribute	...
5	null_no_attribute	null_no_attribute	null_no_attribute	null_no_attribute	...

Table 16 – Continued

	Waitlist	Days	TimeBegin	TimeEnd	...
0	null_no_value	TuTh	11:00am	12:15pm	...
1	0	Tu	6:30pm	9:00pm	...
2	null_no_value	TuTh	11:00am	12:15pm	...
3	null_no_attribute	null_no_attribute	null_no_attribute	null_no_attribute	...
4	null_no_attribute	null_no_attribute	null_no_attribute	null_no_attribute	...
5	null_no_attribute	null_no_attribute	null_no_attribute	null_no_attribute	...

Table 16 – Continued

	Room	Semester	Homepage	...
0	CSI 1121	null_no_attribute	null_no_attribute	...
1	CSI 2117	null_no_attribute	null_no_attribute	...
2	CSI 2118	null_no_attribute	null_no_attribute	...
3	null_no_attribute	null_no_value	http://www.iks.inf.ethz.ch/education/ss04/PDDBS	...
4	null_no_attribute	null_no_value	http://www.dbs.ethz.ch/∼xml	...
5	null_no_attribute	null_no_value	http://www.dbs.ethz.ch/∼ordb	...

Table 16 – Continued

	Sprache	Umfang	UnterrichtTyp
0	null_no_attribute	null_no_attribute	null_no_attribute
1	null_no_attribute	null_no_attribute	null_no_attribute
2	null_no_attribute	null_no_attribute	null_no_attribute
3	Englisch	2V1U	Informatik Vertiefung
4	Deutsch	2V1U	Informatik Vertiefung
5	Deutsch	2V1U	Informatik Vertiefung

7 Benchmark Query 6: Nulls

Conflict: In this THALIA query, all textbooks for courses about verification theory are demanded. The given course data for this query is from the University of Toronto[13] and Carnegie Mellon University. The challenge for the data integration system here is the proper treatment of null values, i.e., to support different meanings of "null".

[13] http://www.cs.toronto.edu

Source Data: See Table 17 (IConcept UniTorontoCSCourse), Table 18 (IConcept UniTorontoCSInstructor), Table 3 (IConcept CarnegieMellonCSCourse), and Table 4 (IConcept CarnegieMellonCSLecturer).

Table 17: University of Toronto Courses (IConcept UniTorontoCSCourse)

	No	Level	OfferedTerm	Title	...
0	CSC 2103/407	cross-listed	Fall 2003	Software Architecture and Design	...
1	CSC 2104/465	cross-listed	Fall 2003	Formal Methods of Program Design	...
2	CSC 2105/408	cross-listed	Fall 2003	Software Engineering	...
3	CSC 2108	graduate	Fall 2003	Automated Verification	...
4	CSC 2204/468	cross-listed	Fall 2003	Operating Systems	...
5	CSC 2209/458	cross-listed	Fall 2003/2004	Computer Networks	...
6	CSC 2221	graduate	Fall 2003	Topics in the Theory of Distributed Systems	...
7	CSC 2228	graduate	Fall 2003	Topics in Mobile and Pervasive Computing	...
8	CSC 2306/456	cross-listed	Fall 2003	High-Performance Scientific Computing	...
9	CSC 2307	graduate	Fall 2003	Numerical Software	...
10	CSC 2401	graduate	Fall 2003/2004	Introduction to Computational Complexity	...
11	CSC 2404/438	cross-listed	Fall 2003/2004	Computability and Logic	...
12	CSC 2405/448	cross-listed	Fall 2003/2004	Automata Theory	...
13	CSC 2414	graduate	Fall 2003/2004	Expander graphs and their Applications	...
14	CSC 2416	graduate	Fall 2003/2004	Machine Learning Theory	...
15	CSC 2423	graduate	Fall 2003/2004	Finite Model Theory and Descriptive Complexity	...
16	CSC 2429	graduate	Fall 2003/2004	Dynamic Data Structure	...
17	CSC 2501/485	cross-listed	Fall 2003/2004	Introduction to Computational Linguistics	...
18	CSC 2502/486	cross-listed	Fall 2003/2004	Introduction to Knowledge Representation	...
19	CSC 2503/487	cross-listed	Fall 2003/2004	Computational Vision I	...
20	CSC 2504/418	cross-listed	Fall 2003/2004	Computer Graphics	...
21	CSC 2504/418	cross-listed	Fall 2003/2004	Computer Graphics	...
22	CSC 2514/428	cross-listed	Fall 2003/2004	Human-Computer Interaction	...
23	CSC 2515	graduate	Fall 2003/2004	Machine Learning	...
24	CSC 2519	graduate	Fall 2003/2004	Natural Language Semantics	...
25	CSC 2521	graduate	Fall 2003/2004	Topics in Computer Graphics: Machine Learning	...
26	CSC 2524	graduate	Fall 2003/2004	Topic in Interactive Computing	...
27	CSC 2525	graduate	Fall 2003/2004	Querying peer-to-peer databases	...
28	CSC 2541	graduate	Fall 2003/2004	Topics in Machine Learning	...
29	CSC 2103/407	cross-listed	Winter 2003/2004	Software Architecture And Design	...
30	CSC 2106	graduate	Winter 2003/2004	Requirement Engineering	...
31	CSC 2105/408	cross-listed	Winter 2003/2004	Software Engineering	...
32	CSC 2107/488	cross-listed	Winter 2003/2004	Language Processors	...
33	CSC 2206	graduate	Winter 2003/2004	Computer System Modelling	...
34	CSC 2209/458	cross-listed	Winter 2003/2004	Computer Networks	...
35	CSC 2302	graduate	Winter 2003/2004	Initial Value Methods For ODEs	...

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	No	Level	OfferedTerm	Title	...
36	CSC 2321	graduate	Winter 2003/2004	Matrix Calculations	...
37	CSC 2410	graduate	Winter 2003/2004	Algorithms in Graph Theory	...
38	CSC 2415	graduate	Winter 2003/2004	Theoretical Aspects of Concurrent Programming	...
39	CSC 2426	graduate	Winter 2003/2004	Topics in Cryptography	...
40	CSC 2427	graduate	Winter 2003/2004	Topics in Graph Theory	...
41	CSC 2506/412	cross	Winter 2003/2004	Probabilistic Reasoning	...
42	CSC 2504/418	cross-listed	Winter 2003/2004	Computer Graphics	...
43	CSC 2504/418	cross-listed	Winter 2003/2004	Computer Graphics	...
44	CSC 2510	graduate	Winter 2003/2004	Conceptual Modeling	...
45	CSC 2509	graduate	Winter 2003/2004	Data Management Systems	...
46	CSC 2511/401	cross-listed	Winter 2003/2004	Natural Language Computing	...
47	CSC 2512	graduate	Winter 2003/2004	Constraint Satisfaction Problems	...
48	CSC 2520	graduate	Winter 2003/2004	The Computational Lexicon	...
49	CSC 2521	graduate	Winter 2003/2004	Topics in Computer Graphics: Artificial Life	...
50	CSC 2523	graduate	Winter 2003/2004	Computational Vision II	...
51	CSC 2527/454	cross-listed	Winter 2003/2004	The Business of Software	...
52	CSC 2528	graduate	Winter 2003/2004	Topics in Computational Linguistics	...
53	CSC 2529	graduate	Winter 2003/2004	Computer Animation	...
54	CSC 2530	graduate	Winter 2003/2004	Visual Modeling	...
55	CSC 2535	graduate	Winter 2003/2004	Computation in Neural Networks	...

Table 17 – Continued

	Location	CourseWebsite	...
0	BA1170	http://www.cs.toronto.edu/∼matz/instruct/csc407/	...
1	BA5224	http://www.cs.toronto.edu/∼hehner/csc465/	...
2	BA 1180	http://www.cdf.toronto.edu/∼csc408h/fall/	...
3	Pratt 266	http://www.cs.toronto.edu/∼chechik/courses03/csc2108/	...
4	BA 1170	http://www.cs.toronto.edu/∼gsg/468/	...
5	BA 1240	http://www.cs.toronto.edu/∼marbach/csc458_F03.html	...
6	BA 1200	http://www.cs.toronto.edu/∼vassos/teaching/2221/	...
7	BA 5256	http://www.cs.toronto.edu/∼delara/courses/csc2228/	...
8	LM 155	http://www.cs.toronto.edu/∼ccc/Courses/cs456-2306.html	...
9	BA 2155	http://www.cs.toronto.edu/∼krj/courses/2307/	...
10	GB 412	http://www.cs.toronto.edu/∼bor/2401f03/index.html	...
11	BA 2156	http://www.cs.toronto.edu/∼sacook/csc438h/	...
12	SS 1072	http://www.cs.toronto.edu/∼toni/Courses/448-2003/CS448.html	...
13	HA 316	http://www.cs.toronto.edu/∼shlomoh/ExpandersF03.html	...
14	GB 220	http://www.cs.toronto.edu/∼toni/Courses/MLTheory/ML.html	...
15	BA 2135	http://www.cs.toronto.edu/∼libkin/csc2423/f03/	...
16	GB 412	http://www.cs.toronto.edu/∼fich/DDS.html	...
17	SS 2129	http://www.cs.toronto.edu/∼suzanne/2501/	...
18	SS 2130	http://www.cs.toronto.edu/∼hector/Courses/2502F03/	...
19	UC 85	http://www.cs.toronto.edu/∼jepson/csc2503/	...
20	BA 1190	http://www.cdf.toronto.edu/∼tnicholl/csc418/syllabus.htm	...

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	Location	CourseWebsite	...
21	BA 1180	http://www.dgp.toronto.edu/~karan/courses/csc418/fall_2003/syllabus.html	...
22	BA 1210	http://www.dgp.toronto.edu/~ravin/courses/csc428f2003/	...
23	HA 316	http://www.cs.toronto.edu/~roweis/csc2515/info.html	...
24	BA 2135	http://www.cs.toronto.edu/~gpenn/csc2519/	...
25	SS 1080	http://www.dgp.toronto.edu/~hertzman/courses/csc2521/fall_2003/	...
26	BA 2587	http://www.dgp.toronto.edu/~ravin/courses/csc2524f2003/	...
27	BA 5256	http://www.cs.toronto.edu/~miller/2525/	...
28	BA 2135	http://www.cs.toronto.edu/~zemel/Courses/csc2541.html	...
29	BA 1170	null_no_value	...
30	UC 69	null_no_value	...
31	null_no_value	null_no_value	...
32	null_no_value	null_no_value	...
33	KP 213	null_no_value	...
34	null_no_value	null_no_value	...
35	BA 2179	null_no_value	...
36	BL 327	null_no_value	...
37	WE 74	null_no_value	...
38	WE 75	null_no_value	...
39	null_no_value	null_no_value	...
40	UC 257	null_no_value	...
41	null_no_value	null_no_value	...
42	null_no_value	null_no_value	...
43	null_no_value	null_no_value	...
44	null_no_value	null_no_value	...
45	SS 1083	null_no_value	...
46	null_no_value	null_no_value	...
47	null_no_value	null_no_value	...
48	null_no_value	null_no_value	...
49	MS 2290	null_no_value	...
50	WB 258	null_no_value	...
51	TBA	null_no_value	...
52	UC 248	null_no_value	...
53	BA 2159	null_no_value	...
54	BA 5287	null_no_value	...
55	KP 113	null_no_value	...

Table 17 – Continued

	Prereq	Text
0	CSC340H (Information Systems Analysis and Design), CSC378H (Data Structures and Algorithm Analysis)	Design Patterns: Elements of Reusable Object-Oriented Software, Gamma et. al. Addison-Wesley (Professional Computing Series), 1995 ISBN 0-201-63361-2
1	null_no_value	E.C.R. Hehner, A Practical Theory of Programming, second edition, Springer, 2003
2	CSC340, CSC378, or equivalent	Hans van Vliet, Software Engineering - Principles and Practice (2nd ed.), John Wiley, 2000.

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	Prereq	Text
3	Graduate standing or permission of instructor. Experience with model-checking and other formal methods, although helpful, is not necessary. However, the course assumes familiarity with basic computer science concepts: relations and functions; boolean and first-order logic (from undergrad discrete-math course), and finite-state machines. You are also expected to have basic knowledge of concurrency. The course includes a number of theoretical and engineering aspects.	'Model Checking', by Clarke, Grumberg, Peled, 1999, MIT Press.
4	CSC258H1, CSC209H1/knowledge of concurrent programming	Applied Operating System Concepts (Windows XP Update), A. Silberschatz, P. B. GAlvin and G. Gagne, Wiley (2003).
5	CSC258H, 354H / 364H / 372H / 378H / ECE385H, STA250H / 255H / 257H / (80% in STA220H / ECO220Y)	Layered network architecture, ARQ retransmission strategies, delay models for data networks, multiaccess communication, routing, congestion control, addressing.
6	null_no_value	null_no_value
7	Basic understanding of operating system principles and knowledge of network programming	null_no_value
8	Elementary calculus: Taylor series, Rolle's theorem, mean value theorem, graphs of functions, continuity, convergence, de l' Hospital's rule, etc.	null_no_value
9	Any previous numerical methods, numerical analysis, or scientific computing course.	The Engineering of Numerical Software, by Webb Miller, Prentice-Hall, 1984. Republished by the Custom Printing Dept., UofT Bookstore.
10	null_no_value	Theory of Computational Complexity, Ding-Zhu Du and Ker-I KO
11	CSC 364/MAT247	null_no_value
12	Some knowledge of computability theory is recommended.	Introduction to the Theory of Computation, by Michael Sipser
13	This course has no prerequisites.	null_no_value
14	The only prerequisite for this course is the equivalent of CS364 (undergraduate complexity	An Introduction to Computational Learning Theory by Kearns and Vazirani.
15	being familiar with the basic notions of first-order propositional and predicate logic (if you took an undergrad logic.	L. Libkin, Elements of Finite Model Theory, 293pp, 1st draft
16	A good undergraduate course in data structures (that focussed on correctness and complexity).	null_no_value
17	a course in AI, knowledge of LISP, or Prolog; or a major in Linguistics; or permission of the instructor.	Jurafsky, Daniel, Martin, James H. Speech and Language Processing. Prentice-Hall, 2000.
18	a course in AI and working knowledge of LISP and PROLOG	A hardcopy of the text for the course, a draft of a book by Brachman and Levesque, will be distributed in class.
19	MAT235 and CSC324, or equivalents	E. Trucco and A. Verri, Introductory Techniques for 3D Computer Vision, Prentice-Hall, 1998 (ISBN 0-13-261108-2).

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	Prereq	Text
20	proficiency in C, and preferably C++.	F.S. Hill, Jr. Computer Graphics Using OpenGL, Second Edition, Prentice Hall, 2001.
21	proficiency in C, and preferably C++.	F.S. Hill, Jr. Computer Graphics Using OpenGL, Second Edition, Prentice Hall, 2001.
22	CSC318/324/372/378	null_no_value
23	null_no_value	Elements of Statistical Learning, Hastie, Tibsshirani, Friedman.
24	null_no_value	null_no_value
25	CS grads or instructor permission	Information Theory, Inference, and Learning Algorithms, by David MacKay
26	null_no_value	null_no_value
27	null_no_value	null_no_value
28	null_no_value	null_no_value
29	CSC340H (Information Systems Analysis and Design), CSC378H (Data Structures and Algorithm Analysis).	null_no_value
30	CSC408 or permission of the instructor.	null_no_value
31	CSC340, CSC378, or equivalent	null_no_value
32	Courses in data structures and programming languages.	null_no_value
33	Solid knowledge of basic probability theory.	null_no_value
34	null_no_value	null_no_value
35	null_no_value	null_no_value
36	calculus, numerical linear algebra, interpolation, some knowledge of PDEs, programming preferably in FORTRAN.	null_no_value
37	null_no_value	null_no_value
38	This course will be concerned with various aspects of the theory underlying parallel architectures and concurrent programming. The following is a tentative list of topics: formalisms for expressing concurrency including flow expressions, path expressions, Petri nets; relative power of synchronization primitives; critical section solutions; the database consistency problem; language features for concurrent programming; e.g. monitors; proving the correctness of concurrent programs; mapping concurrent programs onto parallel architectures.	null_no_value
39	An introduction to cryptography including rigorous definitions of security, a presentation of the number theoretic background, and applications of number theory to various cryptographic problems.	null_no_value
40	null_no_value	null_no_value
41	null_no_value	null_no_value
42	proficiency in C, and preferably C++.	null_no_value
43	proficiency in C, and preferably C++.	null_no_value
44	null_no_value	null_no_value
45	null_no_value	null_no_value

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	Prereq	Text
46	csc228, sta220/250/257 or equivalents	null_no_value
47	an introductory AI course (CSC384 or equivalent) or permission of the instructor	null_no_value
48	null_no_value	null_no_value
49	null_no_value	null_no_value
50	CSC484 or equivalent, and CSC2503	null_no_value
51	CSC2204 (Operating Systems) or equivalent	null_no_value
52	CSC2501(485) or permission of instructor Possible Preparatory Reading: Review the papers in recent issues of Computational Linguistics, and Proceedings of the annual conferences of the Association for Computational Linguistics.	null_no_value
53	null_no_value	null_no_value
54	CSC2503, 2504, or permission of instructor.	null_no_value
55	Some knowledge of calculus and linear algebra.	null_no_value

Table 18: University of Toronto Instructors (IConcept UniTorontoCSInstructor)

	No	FirstName	LastName
0	CSC 2103/407	Matthew	Zaleski
1	CSC 2104/465	E.C.R.	Hehner
2	CSC 2105/408	David	Wortman
3	CSC 2108	Marsha	Chechik
4	CSC 2204/468	G. S.	Graham
5	CSC 2209/458	P.	Marbach
6	CSC 2221	Sam	Toueg
7	CSC 2221	Vassos	Hadzilacos
8	CSC 2228	Eyal	De Lara
9	CSC 2306/456	Christina C.	Christara
10	CSC 2307	Ken	Jackson
11	CSC 2401	Allan	Borodin
12	CSC 2404/438	S.	Cook
13	CSC 2405/448	Toniann	Pitassi
14	CSC 2414	Shlomo	Hoory
15	CSC 2416	Toniann	Pitassi
16	CSC 2423	Leonid	Libkin
17	CSC 2429	Faith	Fich
18	CSC 2501/485	Suzanne	Stevenson
19	CSC 2502/486	Hector	Levesque
20	CSC 2503/487	Allan	Jepson
21	CSC 2504/418	Tina	Nicholl
22	CSC 2504/418	Karan	Singh
23	CSC 2514/428	Ravin	Balakrishnan
24	CSC 2515	Sam	Roweis
25	CSC 2519	Gerald	Penn
26	CSC 2521	Aaron	Hertzmann
27	CSC 2524	Ravin	Balakrishnan

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	No	FirstName	LastName
28	CSC 2525	Renee	Miller
29	CSC 2541	Richard	Zemel
30	CSC 2103/407	Mathew	Zaleski
31	CSC 2106	Steve	Easterbrook
32	CSC 2105/408	David	Wortman
33	CSC 2107/488	David	Wortman
34	CSC 2206	Peter	Marbach
35	CSC 2209/458	Peter	Marbach
36	CSC 2302	Wayne	Enright
37	CSC 2321	Christina	Christara
38	CSC 2410	Avner	Magen
39	CSC 2415	Sam	Toueg
40	CSC 2415	Vassos	Hadzilacos
41	CSC 2426	Charles	Rackoff
42	CSC 2427	Michael	Molloy
43	CSC 2506/412	Sam	Roweis
44	CSC 2504/418	Demetri	Terzopoulos
45	CSC 2504/418	Aaron	Hertzmann
46	CSC 2510	John	Mylopoulos
47	CSC 2509	Anthony	Bonner
48	CSC 2511/401	Gerald	Penn
49	CSC 2512	Fahiem	Bacchus
50	CSC 2520	Suzanne	Stevenson
51	CSC 2521	Demetri	Terzopoulos
52	CSC 2523	Sven	Dickinson
53	CSC 2527/454	TBA	TBA
54	CSC 2528	Graeme	Hirst
55	CSC 2529	Karan	Singh
56	CSC 2530	Kyros	Kutulakos
57	CSC 2535	Geoffrey	Hinton

Conflict Resolution: In SIQL, an extensible set of null values is supported to express different notions of "null". In particular, null_no_value represents the fact that an attribute exists in the schema of a record but there is no attribute value in the particular record because the value is unknown, inapplicable, or withheld. Furthermore, null_no_attribute expresses that there is no attribute value because the respective attribute does not exist at all in the schema of the corresponding record. Based on these different null values, the special semantics as required in the current benchmark query can be represented. Hence, a SIQL query as follows can be formulated to overcome the challenge of benchmark query 6:

Listing 10: SIQL Solution for THALIA Benchmark Query 6

```
0  select ∗ from (
1          (select c.No, Level, OfferedTerm, Title, Location,
2          CourseWebsite, Prereq, Text, FirstName, LastName from
3                  (select ∗ from UniTorontoCSCourse) as c
4                  inner join
5                  (select ∗ from UniTorontoCSInstructor) as i
6                  on c.No = i.No)
7          outer union
8          (select c.Code as No, c.Sec, CourseX−Listed,
9          CourseTitle as Title, Room as Location, Day, TimeBegin,
10         TimeEnd, Units, Lecturer as LastName from
11                 (select ∗ from CarnegieMellonCSCourse) as c
12                 inner join
13                 (select ∗ from CarnegieMellonCSLecturer) as l
14                 on c.Code = l.Code and l.Sec = c.Sec) )
15 where matches(Title, "(.)∗Verification(.)∗") = true;
```

Result: The requested information on all textbooks for courses about verification theory is shown in the following table (note the title information in the "Title" attribute and, in particular, the special kinds of null values in attribute "Text" for courses whose source data does not have a corresponding attribute with textbook information):

Table 19: Result Data for SIQL Query from Listing 10

	No	Level	OfferedTerm	Title	...
0	CSC 2108	graduate	Fall 2003	Automated Verification	...
1	15-819	null_no_attribute	null_no_attribute	Specification and Verification	...
2	15-819	null_no_attribute	null_no_attribute	Specification and Verification	...
3	15-820	null_no_attribute	null_no_attribute	Verification of Concurrent, Reactive, Real-Time Prgrms	...

Table 19 – Continued

	Location	CourseWebsite	Prereq	...
0	Pratt 266	http://www.cs.toronto.edu/∼chechik/courses03/csc2108/	Graduate standing or permission of instructor. Experience with model-checking and other formal methods, although helpful, is not necessary. However, the course assumes familiarity with basic computer science concepts: relations and functions; boolean and first-order logic (from undergrad discrete-math course), and finite-state machines. You are also expected to have basic knowledge of concurrency. The course includes a number of theoretical and engineering aspects.	...

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	Location	CourseWebsite	Prereq	...
1	WeH 4615A	null_no_attribute	null_no_attribute	...
2	WeH 4615A	null_no_attribute	null_no_attribute	...
3	WeH 4601	null_no_attribute	null_no_attribute	...

Table 19 – Continued

	Text	FirstName	LastName	...
0	'Model Checking', by Clarke, Grumberg, Peled, 1999, MIT Press.	Marsha	Chechik	...
1	null_no_attribute	null_no_attribute	Clarke	...
2	null_no_attribute	null_no_attribute	Reynolds	...
3	null_no_attribute	null_no_attribute	Clarke	...

Table 19 – Continued

	Sec	CourseX-Listed	Day	TimeBegin	...
0	null_no_attribute	null_no_attribute	null_no_attribute	null_no_attribute	...
1	B	.	TR	1:30pm	...
2	B	.	TR	1:30pm	...
3	A	.	W	3:30pm	...

Table 19 – Continued

	TimeEnd	Units
0	null_no_attribute	null_no_attribute
1	2:50pm	12
2	2:50pm	12
3	4:50pm	6

8 Benchmark Query 7: Virtual Columns

Conflict: In the seventh THALIA query, it is necessary to find all entry-level courses. The given course data for this query is from University of Michigan[14] and Arizona State University[15]. The challenge for the data integration system here is to infer from a comment value (i.e., from "Prerequisites" in ArizonaStateCSCourse) that the course is an entry-level course.

[14] http://www.cs.umich.edu

[15] http://cse.asu.edu

Source Data: See Table 20 (IConcept UniMichiganCSCourse) and Table 21 (IConcept ArizonaStateCSCourse). Note that the given sample value used in the description for benchmark query 7 in [HST04] with "None" as its prerequisites does not exist in the benchmark data for University of Michigan; in the given data, the prerequisites attribute value is "EECS 281 or Graduate Standing." (see Record 54 in Table 20).

Table 20: University of Michigan Courses (IConcept UniMichiganCSCourse)

	Subject	CatalogNumber	Name	...
0	EECS	181	Introduction to Computer Systems	...
1	EECS	183	Elementary Programming Concepts	...
2	EECS	203	Discrete Mathematics	...
3	EECS	206	Signals and Systems I	...
4	EECS	215	Introduction to Circuits	...
5	EECS	230	Electromagnetics I	...
6	EECS	250	Electronic Sensing Systems	...
7	EECS	270	Introduction to Logic Design	...
8	EECS	280	Programming and Introductory Data Structures	...
9	EECS	281	Data Structures and Algorithms	...
10	EECS	283	Programming for Science and Engineering	...
11	EECS	284	Introduction to a Programming Language or System	...
12	EECS	285	A Programming Language or Computer System	...
13	EECS	306	Signals and Systems II	...
14	EECS	311	Electronic Circuits	...
15	EECS	312	Digital Integrated Circuits	...
16	EECS	314	Circuit Analysis and Electronics	...
17	EECS	320	Introduction to Semiconductor Devices	...
18	EECS	330	Electromagnetics II	...
19	EECS	334	Principles of Optics	...
20	EECS	353	Introduction to Communications Systems	...
21	EECS	370	Introduction to Computer Organization	...
22	EECS	373	Design of Microprocessor Based Systems	...
23	EECS	376	Foundations of Computer Science	...
24	EECS	381	Object Oriented and Advanced Programming	...
25	EECS	398	Special Topics	...
26	EECS	401	Probabilistic Methods in Engineering	...
27	EECS	411	Microwave Circuits I	...
28	EECS	413	Monolithic Amplifi er Circuits	...
29	EECS	414	Introduction to MEMS	...
30	EECS	417	Electrical Biophysics	...
31	EECS	420	Introduction to Quantum Electronics	...
32	EECS	421	Properties of Transistors	...
33	EECS	423	Solid-State Device Laboratory	...
34	EECS	425	Integrated Microsystems Laboratory	...
35	EECS	427	VLSI Design I	...
36	EECS	429	Semiconductor Optoelectronic Devices	...
37	EECS	430	Radiowave Propagation and Link Design	...
38	EECS	434	Principles of Photonics	...
39	EECS	435	Fourier Optics	...
40	EECS	438	Advanced Lasers and Optics Laboratory	...
41	EECS	442	Computer Vision	...

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	Subject	CatalogNumber	Name	...
42	EECS	451	Digital Signal Processing and Analysis	...
43	EECS	452	Digital Signal Processing Design Laboratory	...
44	EECS	455	Digital Communication Signals and Systems	...
45	EECS	458	Biomedical Instrumentation	...
46	EECS	460	Control Systems Analysis and Design	...
47	EECS	461	Embedded Control Systems	...
48	EECS	470	Computer Architecture	...
49	EECS	477	Introduction to Algorithms	...
50	EECS	478	Logic Circuit Synthesis and Optimization	...
51	EECS	481	Software Engineering	...
52	EECS	482	Introduction to Operating Systems	...
53	EECS	483	Compiler Construction	...
54	EECS	484	Database Management Systems	...
55	EECS	485	Web Database and Information Systems	...
56	EECS	486	Object-Oriented Methodology	...
57	EECS	487	Interactive Computer Graphics	...
58	EECS	489	Computer Networks	...
59	EECS	492	Introduction to Artifi cial Intelligence	...
60	EECS	493	User Interface Development	...
61	EECS	494	Computer Game Design and Development	...
62	EECS	496	Major Design Experience Professionalism	...
63	EECS	497	EECS Major Design Projects	...
64	EECS	498	Special Topics	...
65	EECS	499	Directed Study	...
66	EECS	500	Tutorial Lecture Series in System Science	...
67	EECS	501	Probability and Random Processes	...
68	EECS	502	Stochastic Processes	...
69	EECS	503	Introduction to Numerical Electromagnetics	...
70	EECS	506	Computing System Evaluation	...
71	EECS	509	Traffi c Modeling	...
72	EECS	510	Intelligent Transportation Systems Research Topics	...
73	EECS	512	Amorphous and Microstayalline Semiconductor Thin Film Devices	...
74	EECS	513	Flat Panel Displays	...
75	EECS	514	Advanced MEMS Devices and Technologies	...
76	EECS	515	Integrated Microsystems	...
77	EECS	516	Medical Imaging Systems	...
78	EECS	517	Physical Processes in Plasmas	...
79	EECS	518	Magnetosphere and Solar Wind	...
80	EECS	519	Plasma Generation and Diagnostics Laboratory	...
81	EECS	520	Electronic and Optical Properties of Semiconductors	...
82	EECS	521	High-Speed Transistors	...
83	EECS	522	Analog Integrated Circuits	...
84	EECS	523	Digital Integrated Technology	...
85	EECS	524	Field-Effect-Transistors and Microwave Monolithic Integrated Circuits Technology	...
86	EECS	525	Advanced Solid State Microwave Circuits	...
87	EECS	526	High-Performance Dynamic Device Models and Circuits	...
88	EECS	527	Layout Synthesis and Optimization	...
89	EECS	528	Principles of Microelectronics Process Technology	...

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	Subject	CatalogNumber	Name	...
90	EECS	529	Semiconductor Lasers and LEDs	...
91	EECS	530	Electromagnetic Theory I	...
92	EECS	531	Antenna Theory and Design	...
93	EECS	532	Microwave Remote Sensing I: Radiometry	...
94	EECS	533	Microwave Measurements Laboratory	...
95	EECS	534	Design and Characterization of Microwave Devices and Monolithic Circuits	...
96	EECS	535	Optical Information Processing	...
97	EECS	536	Classical Statistical Optics	...
98	EECS	537	Classical Optics	...
99	EECS	538	Optical Waves in Crystals	...
100	EECS	539	Lasers	...
101	EECS	540	Applied Quantum Mechanics I	...
102	EECS	541	Applied Quantum Mechanics II	...
103	EECS	542	Vision Processing	...
104	EECS	543	Knowledge-Based Systems	...
105	EECS	545	Machine Learning	...
106	EECS	546	Ultrafast Optics	...
107	EECS	547	Electronic Commerce	...
108	EECS	550	Information Theory	...
109	EECS	551	Wavelets and Time-Frequency Distribution	...
110	EECS	552	Fiber Optical Communications	...
111	EECS	554	Introduction to Digital Communication and Coding	...
112	EECS	555	Digital Communication Theory	...
113	EECS	556	Image Processing	...
114	EECS	557	Communication Networks	...
115	EECS	558	Stochastic Control	...
116	EECS	559	Advanced Signal Processing	...
117	EECS	560	Linear Systems Theory	...
118	EECS	561	Design of Digital Control Systems	...
119	EECS	562	Nonlinear Systems and Control	...
120	EECS	564	Estimation, Filtering, and Detection	...
121	EECS	565	Linear Feedback Control Systems	...
122	EECS	567	Introduction to Robotics: Theory and Practice	...
123	EECS	570	Parallel Computer Architecture	...
124	EECS	571	Principles of Real-Time Computing	...
125	EECS	573	Microarchitecture	...
126	EECS	574	Theoretical Computer Science	...
127	EECS	575	Advanced Cryptography	...
128	EECS	577	Reliable Computing Systems	...
129	EECS	578	Computer-Aided Design Verifi cation of Digital Systems	...
130	EECS	579	Digital System Testing	...
131	EECS	581	Software Engineering Tools	...
132	EECS	582	Advanced Operating Systems	...
133	EECS	583	Advanced Compilers	...
134	EECS	584	Advanced Database Systems	...
135	EECS	585	Web Technologies	...
136	EECS	586	Design and Analysis of Algorithms	...
137	EECS	587	Parallel Computing	...
138	EECS	589	Advanced Computer Networks	...

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	Subject	CatalogNumber	Name	...
139	EECS	591	Distributed Systems	...
140	EECS	592	Advanced Artifi cial Intelligence	...
141	EECS	594	Introduction to Adaptive Systems	...
142	EECS	595	Natural Language Processing	...
143	EECS	596	Master of Engineering Team Project	...
144	EECS	597	Language and Information	...
145	EECS	598	Special Topics in Electrical Engineering and Computer Science	...
146	EECS	599	Directed Study	...
147	EECS	600	Function Space Methods in System Theory	...
148	EECS	623	Integrated Sensors and Sensing Systems	...
149	EECS	627	VLSI Design II	...
150	EECS	631	Electromagnetic Scattering	...
151	EECS	632	Microwave Remote Sensing II - Radar	...
152	EECS	633	Numerical Methods in Electromagnetics	...
153	EECS	634	Nonlinear Optics	...
154	EECS	638	Quantum Theory of Light	...
155	EECS	643	Theory of Neural Computation	...
156	EECS	644	Computational Modeling of Cognition	...
157	EECS	650	Channel Coding Theory	...
158	EECS	651	Source Coding Theory	...
159	EECS	658	Fast Algorithms for Signal Processing	...
160	EECS	659	Adaptive Signal Processing	...
161	EECS	661	Discrete Event Systems	...
162	EECS	662	Advanced Nonlinear Control	...
163	EECS	670	Special Topics in Computer Architecture	...
164	EECS	674	Special Topics in Theoretical Computer Science	...
165	EECS	682	Special Topics in Software Systems	...
166	EECS	684	Current Topics in Databases	...
167	EECS	692	Special Topics in Artifi cial Intelligence	...
168	EECS	695	Neural Models and Psychological Processes	...
169	EECS	698	Master's Thesis	...
170	EECS	699	Research Work in Electrical Engineering and Computer Science	...
171	EECS	700	Special Topics in System Theory	...
172	EECS	720	Special Topics in Solid-State Devices,Integrated Circuits, and Physical Electronics	...
173	EECS	730	Special Topics in Electromagnetics	...
174	EECS	731	Space Terahertz Technology and Applications	...
175	EECS	735	pecial Topics in the Optical Sciences	...
176	EECS	750	Special Topics in Communication and Information Theory	...
177	EECS	755	Special Topics in Signal Processing	...
178	EECS	760	Special Topics in Control Theory	...
179	EECS	765	Special Topics in Stochastic Systems and Control	...
180	EECS	770	Special Topics in Computer Systems	...
181	EECS	800	Seminar in Optical Science and Engineering	...
182	EECS	820	Seminar in Solid-State Electronics	...
183	EECS	892	Seminar in Artifi cial Intelligence	...
184	EECS	990	Dissertation/Pre-Candidate	...

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	Subject	CatalogNumber	Name	...
185	EECS	995	Dissertation/Candidate	...

Table 20 – Continued

	Prerequisite	Field	Credits	...
0	none	I	4	...
1	none. (Credit for only one: EECS 183, Eng 101)	I	4	...
2	Math 115	I	4	...
3	Math 116, Eng 101	I	4	...
4	Math 116, PHYS 240 (or 260), preceded or accompanied by Math 216 and EECS 206 Cannot receive credit for EECS 210 and EECS 215.	I	4	...
5	Math 215, PHYS 240 (or 260) and EECS 215	I	4	...
6	preceded or accompanied by EECS 230 or Physics 240	II	3	...
7	EECS 183 or Eng 101 or equivalent	I	4	...
8	Math 115 and prior programming experience.	I	4	...
9	EECS 203 and 280.	I	4	...
10	EECS 183 or Eng 101 or equivalent.	II	4	...
11	some programming knowledge.	I	1	...
12	some programming experience.	I	2	...
13	Math 216, EECS 206, and (EECS 215 or EECS 314)	I	4	...
14	EECS 215 and EECS 320	I	4	...
15	EECS 215 and EECS 320	II	4	...
16	Math 216 and Physics 240. A student can receive credit for only one: EECS 210, 215, 314	I	4	...
17	PHYS 240 or 260	I	4	...
18	EECS 230.	I	4	...
19	Physics 240. A student can receive credit for only one: EECS 334 or Physics 402.	II	4	...
20	EECS 212/316 or EECS 306.	II	4	...
21	(EECS 203 or EECS 270) and (EECS 280 or EECS 283).	I	4	...
22	EECS 270 and 370 and Junior Standing.	I	4	...
23	EECS 203 and 280 or equivalent.	I	4	...
24	EECS 281.	II	4	...
25	permission of instructor.	null_no_value	4	...
26	EECS 306 or 212/316 or Graduate Standing.	I	4	...
27	EECS 330 or Graduate Standing.	I	4	...
28	EECS 311 and EECS 320 or Graduate Standing.	II	4	...
29	Math 215, Math 216, Physics 240 or graduate standing.	I	4	...
30	EECS 206 and 215 or Graduate Standing.	I	4	...
31	(EECS 320 and EECS 330 or equivalent) or Graduate Standing.	I	4	...
32	EECS 320 or Graduate Standing.	I	3	...
33	EECS 320 or Graduate Standing.	I	4	...
34	EECS 311 or EECS 312 or EECS 414 or Graduate Standing.	II	4	...
35	EECS 270 and EECS 312	I	4	...

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	Prerequisite	Field	Credits	...
36	EECS 320 or Graduate Standing.	II	4	...
37	EECS 330 and Senior Standing or Graduate Standing.	II	4	...
38	EECS 330 or EECS 334 or permission of instructor or Graduate Standing.	I	4	...
39	EECS 211/316 or EECS 306 preceded or accompanied by EECS 334 and Junior Standing.	II	3	...
40	EECS 334 or EECS 434 or Graduate Standing.	II	4	...
41	EECS 281 or Graduate Standing.	I	4	...
42	EECS 212/316 or EECS 306.	I	4	...
43	(EECS 212/316 or 306) and EECS 280, or Graduate Standing.	I	4	...
44	(EECS 212/316 or EECS 306) and EECS 401.	I	3	...
45	EECS 215 or 314 or consent of instructor or Graduate Standing.	II	4	...
46	EECS 212/316 or EECS 306 or Graduate Standing.	I	3	...
47	EECS 306 or EECS 373 or Graduate Standing.	I	4	...
48	EECS 370 and EECS 270, or Graduate Standing.	I	4	...
49	EECS 281 or Graduate Standing.	I	4	...
50	(EECS 203, EECS 270, and Senior Standing) or Graduate Standing.	I	4	...
51	EECS 281 or Graduate Standing.	I	4	...
52	EECS 281 and EECS 370 or Graduate Standing.	I	4	...
53	EECS 281 or Graduate Standing.	I	4	...
54	EECS 281 or Graduate Standing.	I	4	...
55	EECS 484 or permission of instructor or Graduate Standing.	II	4	...
56	EECS 281 or Graduate Standing.	I	4	...
57	EECS 281 and Senior Standing or Graduate Standing.	I	4	...
58	EECS 482 or Graduate Standing.	I	4	...
59	EECS 281 or Graduate Standing.	I	4	...
60	EECS 281 or Graduate Standing.	II	4	...
61	EECS 281 or Graduate Standing.	I	4	...
62	Senior Standing.	I	2	...
63	Senior Standing and successful completion of at least two-thirds of the credit hours required for the program subjects.	I	4	...
64	permission of instructor.	null_no_value	1 4	...
65	Senior Standing in EECS.	I	1 4	...
66	Graduate Standing; mandatory satisfactory/ unsatisfactory.	I	1	...
67	EECS 401 or Graduate Standing.	I	4	...
68	EECS 501	I	3	...
69	EECS 330	I	3	...
70	EECS 183 or EECS 280, and EECS 370 and EECS 501. II odd years	null_no_value	3	...
71	IOE 316, Stat 310, or EECS 401	I	3	...
72	two ITS-Certifi cate courses (may be taken concurrently)	II	2	...
73	EECS 421 and/or permission of instructor.	I	3	...
74	EECS 423, EECS 512 and/or permission of instructor.	II	3	...
75	EECS 414.	II	4	...

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	Prerequisite	Field	Credits	...
76	EECS 414	I	4	...
77	EECS 451	I	3	...
78	EECS 330	II	3	...
79	Graduate Standing.	I	3	...
80	preceded or accompanied by a course covering electromagnetism. II	II	4	...
81	EECS 420 or EECS 540. II	II	4	...
82	EECS 421 or EECS 422. II	II	3	...
83	EECS 413	II	4	...
84	EECS 423 or 425 and EECS 311 and EECS 320.	I	4	...
85	Graduate Standing and EECS 421, and either EECS 525 or EECS 528.	II	3	...
86	EECS 411, EECS 421 or EECS 521	I	3	...
87	EECS 413, or both EECS 311 and EECS 320.	II	4	...
88	EECS 478	II	3	...
89	EECS 421, EECS 423.	II	3	...
90	EECS 429.	I	3	...
91	EECS 330 or Physics 438.	I	3	...
92	EECS 330	II	3	...
93	EECS 330, Graduate Standing	I	3	...
94	EECS 330, Graduate Standing.	II	3	...
95	Graduate Standing, EECS 421 or EECS 525	I	3	...
96	EECS 334.	I	3	...
97	EECS 334 or EECS 434, and EECS 401 or Math 425.	I	3	...
98	EECS 330 and EECS 334	I	3	...
99	EECS 434	I	3	...
100	EECS 537 and EECS 538	II	3	...
101	permission of instructor	I	3	...
102	EECS 540.	II	3	...
103	EECS 442	I	3	...
104	EECS 281 and Graduate Standing or permission of instructor. I	null_no_value	3	...
105	EECS 492	null_no_value	3	...
106	EECS 537	II	3	...
107	EECS 281 or SI 502 or permission of instructor.	I	3	...
108	EECS 501	null_no_value	3	...
109	EECS 451	I	3	...
110	EECS 434 or EECS 538 or permission of instructor.	II	3	...
111	EECS 212/316 or 306 and EECS 401.	I	3	...
112	EECS 501, EECS 554.	II	3	...
113	EECS 451, EECS 501.	II	3	...
114	Graduate Standing, preceded by EECS 401 or accompanied by EECS 501.	I	3	...
115	EECS 501, EECS 560	I	3	...
116	EECS 451, EECS 501	II	3	...
117	Graduate Standing	I	4	...
118	EECS 460 or Aero 471 or ME 461.	I	4	...
119	Graduate Standing.	II	3	...
120	EECS 501.	II	3	...

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	Prerequisite	Field	Credits	...
121	EECS 460 or Aero 345 or ME 461 and Aero 550 (EECS 550).	II	3	...
122	EECS 281.	II	3	...
123	EECS 470.	I	4	...
124	EECS 470, EECS 482 or permission of instructor.	I	3	...
125	EECS 470 or permission of instructor.	I	3	...
126	EECS 376	I	4	...
127	EECS 203 or equivalent (EECS 574 recommended)	II	4	...
128	EECS 280 and EECS 478.	null_no_value	3	...
129	EECS 478	II	3	...
130	Graduate Standing.	I	3	...
131	EECS 481 or equivalent programming experience. II	II	3	...
132	EECS 482	II	4	...
133	EECS 281 and 370 (EECS 483 is also recommended)	II	4	...
134	EECS 484	I	4	...
135	EECS 482 or EECS 485 or permission of instructor.	I	3	...
136	EECS 281	II	3	...
137	EECS 281 and Graduate Standing	I	3	...
138	EECS 489.	II	4	...
139	EECS 482 and Graduate Standing.	I	4	...
140	EECS 492 or permission of instructor.	II	4	...
141	EECS 203, Math 425 (Stat 425).	II	3	...
142	Senior Standing.	I	3	...
143	enrollment in the Masters of Engineering program in EECS. I, II, IIIa, IIIb, and III	I	1 6	...
144	SI 503 or EECS 281 and Graduate Standing or permission of instructor	I	3	...
145	permission of instructor or counselor.	I	1 4	...
146	prior arrangement with instructor; mandatory satisfactory/unsatisfactory.	I	1 4	...
147	Math 419.	II	3	...
148	EECS 413, and either EECS 423, or EECS 425, or EECS 523	I	4	...
149	EECS 427.	I	4	...
150	EECS 530 and Graduate Standing.	I	3	...
151	EECS 532.	II	3	...
152	EECS 530.	I	3	...
153	EECS 537 or EECS 538 or EECS 530.	I	3	...
154	quantum mechanics electrodynamics and atom physics.	II	3	...
155	Graduate Standing or permission of instructor.	II	2 4	...
156	Graduate Standing or permission of instructor.	II	2 4	...
157	EECS 501 and Math 419.	II	3	...
158	EECS 501.	II	3	...
159	EECS 451, EECS 501.	I	2 4	...
160	EECS 559.	I	2 4	...
161	Graduate Standing.	I	2 4	...
162	EECS 562 or ME 548.	I	3	...
163	permission of instructor.	null_no_value	3	...
164	permission of instructor.	null_no_value	3	...
165	permission of instructor.	null_no_value	3	...

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	Prerequisite	Field	Credits	...
166	EECS 484	I	3	...
167	permission of instructor.	null_no_value	3	...
168	permission of instructor.	II	3	...
169	election of an EECS master's thesis option.	I	1 6	...
170	Graduate Standing, permission of instructor; mandatory satisfactory/unsatisfactory.	I	1 6	...
171	permission of instructor (to be arranged)	null_no_value	null_no_value	...
172	permission of instructor.	null_no_value	1 4	...
173	permission of instructor.(to be arranged)	null_no_value	1 4	...
174	permission of instructor; mandatory satisfactory/unsatisfactory.	I	1	...
175	Graduate Standing, permission of instructor (to be arranged)	null_no_value	1 4	...
176	permission of instructor. (to be arranged)	null_no_value	null_no_value	...
177	permission of instructor. (to be arranged)	null_no_value	1 4	...
178	permission of instructor. (to be arranged)	null_no_value	null_no_value	...
179	permission of instructor. (to be arranged)	null_no_value	3	...
180	permission of instructor. (to be arranged)	null_no_value	null_no_value	...
181	Graduate Standing.	I	1	...
182	Graduate Standing, permission of instructor.	I	1	...
183	EECS 592 or equivalent.	I	2	...
184	null_no_value	I	2 8	...
185	Graduate School authorization for admission as a doctoral candidate.	I	8	...

Table 20 – Continued

	Description
0	Fundamental computer skills needed to increase productivity. Use of software packages and applications including word processors, web browsers, spreadsheets, database systems. Creating a web home page. History of computing, ethics and legal issues. Introduction to basic hardware components. Intended for non CE/CS/EE majors whose goal is computer literacy.
1	Fundamental concepts and skills of programming in a high-level language. Flow of control: selection, iteration, subprograms. Data structures: strings, arrays, records, lists, tables. Algorithms using selection and iteration (decision making, fi nding maxima/minima, searching, sorting, simulation, etc.) Good program design, structure and style are emphasized. Testing and debugging. Not intended for Engineering students (who should take ENGR 101), nor for CS majors in LSA who qualify to enter EECS 280.
2	Introduction to the mathematical foundations of computer science. Topics covered include: propositional and predicate logic, set theory, function and relations, growth of functions and asymptotic notation, introduction to algorithms, elementary combinatorics and graph theory, and discrete probability theory.
3	Introduction to theory and practice of signals and systems engineering in continuous and discrete time. Hands-on experience with representative engineering tasks in laboratory sessions involving audio, images, and other signals. Time-domain concepts: energy, power, periodicity, fi ltering, linear system, convolution, correlation, detection, modulation, sampling, quantization, histogram. Frequency-domain concepts: sinusoids, exponentials, Fourier series, Fourier transform, frequency response. Digital processing of analog signals.

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	Description
4	Introduction to electrical circuits. Kirchhoff's voltage and current laws; Ohm's law; voltage and current sources; Thevenin and Norton equivalent circuits; energy and power. Time-domain and frequency-domain analysis of RLC circuits. Operational amplifi er circuits. Basic passive and active electronic fi lters. Laboratory experience with electrical signals and circuits.
5	Electric charge and current. Traveling waves and phasors. Transmission lines; sinusoidal analysis and transient response. Vector calculus. Electrostatics. Magnetostatics. Laboratory segment includes experiments with transmission lines, the use of computer-simulation exercises, and classroom demonstrations.
6	Introduction to properties and behavior of electromagnetic energy as it pertains to naval applications of communication, radar, and electro-optics. Additional topics include sound navigation and ranging (SONAR) tracking and guidance systems, and computer controlled systems. Several laboratory demonstrations will illustrate applications of the theories and concepts learned in the classroom.
7	Binary and non-binary systems, Boolean algebra digital design techniques, logic gates, logic minimization, standard combinational circuits, sequential circuits, fl ip-fl ops, synthesis of synchronous sequential circuits, PLAs, ROMs, RAMs, arithmetic circuits, computer-aided design. Laboratory includes hardware design and CAD experiments.
8	Techniques and algorithm development and effective programming, top-down analysis, structured programming, testing, and program correctness. Program language syntax and static and runtime semantics. Scope, procedure instantiation, recursion, abstract data types, and parameter passing methods. Structured data types, pointers, linked data structures, stacks, queues, arrays, records, and trees.
9	Introduction to algorithm analysis and O-notation; Fundamental data structures including lists, stacks, queues, priority queues, hash tables, binary trees, search trees, balanced trees and graphs; searching and sorting algorithms; recursive algorithms; basic graph algorithms; introduction to greedy algorithms and divide and conquer strategy. Several programming assignments.
10	Programming concepts with numeric applications for mathematics, the sciences, and engineering. Object-oriented programming, abstract data types, and standard class libraries with numeric and non-numeric applications. Elementary data structures, linked lists, and dynamic allocation. Searching and sorting methods. Not intended for CS majors.
11	A minicourse covering a complex computer system or programming language. Specifi c languages or systems to be offered will be announced in advance.
12	A course covering a complex computer system or programming language. Programming problems will be assigned. Specifi c languages or systems to be offered will be announced in advance.
13	Theory and practice of signals and systems engineering in continuous and discrete time. Hands-on experience in laboratory sessions with communications, control and signal processing. Continuous-time linear systems: convolution, Fourier and Laplace transforms, transfer functions, poles and zeros, stability, sampling, introductions to communications and feedback control. Discrete-time linear systems: Z transform, fi lters, Fourier transform, signal processing. State space models of systems using fi nite-state machines.
14	Circuit models for bipolar junction and fi eld-effect transistors; nonlinear elements; small-signal and piecewise analysis of nonlinear circuits; analysis and design of basic single-stage transistor amplifi ers: gain, biasing, and frequency response; digital logic circuits; memory circuits (RAM, ROM). Design projects. Lecture and laboratory.
15	Design and analysis of static CMOS inverters and complex combinational logic gates. Dynamic logic families, pass-transistor logic, ratioed logic families. Sequential elements (latches, fl ip-fl ops). Bipolar-based logic; ECL, BiCMOS. Memories; SRAM, DRAM, EEPROM, PLA. I/O circuits and interconnect effects. Design project(s). Lecture, recitation and software labs.

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	Description
16	A survey of electrical and electronic circuits for students not in EE or CE. Formulation of circuit equations; equivalent circuits; frequency response ideas; steady-state and transient response; introduction to amplifi ers; operational amplifi ers; survey of electronic devices and circuits. Use of computer simulations for analysis of more advanced circuits.
17	Introduction to semiconductors in terms of atomic bonding and electron energy bands. Equilibrium statistics of electrons and holes. Carrier dynamics; continuity, drift, and diffusion currents; generation and recombination processes, including important optical processes. Introduction to: PN junctions, metalsemiconductor junctions, light detectors and emitters; bipolar junction transistors, junction and MOSFETs.
18	Time-varying electromagnetic fi elds and Maxwell's equations. Plane-wave propagation, refl ection, and transmission. Geometric optics. Radiation and antennas. System applications of electromagnetic waves. Laboratory segment consists of experiments involving microwave and optical measurements and the design of practical systems.
19	Basic principles of optics: light sources and propagation of light; geometrical optics, lenses and imaging; ray tracing and lens aberrations; interference of light waves, coherent and incoherent light beams; Fresnel and Fraunhofer diffraction. Overview of modern optics with laboratory demonstrations.
20	Mathematical analysis of signals and signal processing used in analog and digital communication systems; sampling; quantization; pulse transmission; intersymbol interference; Nyquist criterion; partial response signals; eye diagrams; equalization; mixing; analog modulation and demodulation; receiver architectures; phase-locked loops; signal-to-noise ratio analysis; digital modulation and demodulation; spread spectrum communications.
21	Basic concepts of computer organization and hardware. Instructions executed by a processor and how to use these instructions in simple assembly-language programs. Stored-program concept. Datapath and control for multiple implementations of a processor. Performance evaluation, pipelining, caches, virtual memory, input/output.
22	Principles of hardware and software microcomputer interfacing; digital logic design and implementation. Experiments with specially designed laboratory facilities. Introduction to digital development equipment and logic analyzers. Assembly language programming. Lecture and laboratory.
23	An introduction to computation theory: fi nite automata, regular languages, pushdown automata, context-free languages, Turing machines, recursive languages and functions, and computational complexity.
24	Programming techniques in Standard C++ for large-scale, complex, or high-performance software. Encapsulation, automatic memory management, exceptions, generic programming with templates and function objects, Standard Library algorithms and containers. Using single and multiple inheritance and polymorphism for code reuse and extensibility; basic design idioms, patterns, and notation.
25	Topics of current interest selected by the faculty. Lecture, seminar, or laboratory.
26	Basic concepts of probability theory. Random variables: discrete, continuous, and conditional probability distributions; averages; independence. Introduction to discrete and continuous random processes: wide sense stationarity, correlation, spectral density.
27	Transmission-line theory, microstrip and coplanar lines, S-parameters, signal- fl ow graphs, matching networks, directional couplers, low-pass and band-pass fi lters, diode detectors. Design, fabrication, and measurements (1-10GHz) of microwave-integrated circuits using CAD tools and network analyzers.
28	Analysis and design of BJT and MOS multi-transistor amplifi ers. Feedback theory and application to feedback amplifi ers. Stability considerations, polezero cancellation, root locus techniques in feedback amplifi ers. Detailed analysis and design of BJT and MOS integrated operational amplifi ers. Lectures and laboratory.

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	Description
29	Micro electro mechanical systems (MEMS), devices, and technologies. Micromachining and microfabrication techniques, including planar thin-fi lm processing, silicon etching, wafer bonding, photolithography, deposition, and etching. Transduction mechanisms and modeling in different energy domains. Analysis of micromachined capacitive, piezoresistive, and thermal sensors/actuators and applications. Computer-aided design for MEMS layout, fabrication, and analysis.
30	Electrical biophysics of nerve and muscle; electrical conduction in excitable tissue; quantitative models for nerve and muscle, including the Hodgkin Huxley equations; biopotential mapping, cardiac electrophysiology, and functional electrical stimulation; group projects. Lecture and recitation.
31	Introduction to quantum mechanics of electrons and photons. Electrons in crystals. Metals, semiconductors and insulators. Effective mass, holes, valence and conduction band. Quantum wells, wires and dots. Tunneling effects and applications. Introduction to scattering theory. Charge transport, mobilities in semiconductors. Optical absorption and gain in semiconductors. Physical phenomena discussed in this course will be related to important microelectronic devices.
32	DC, small and large signal AC, switching and power-limiting characteristics, and derivation of equivalent circuit models of: PN junctions, metal-semiconductor and metal-insulator semiconductor diodes, bipolar junction transistors, junction and insulated-gate fi eld-effect transistors, and thyristors.
33	Semiconductor material and device fabrication and evaluation: diodes, bipolar and fi eld-effect transistors, passive components. Semiconductor processing techniques: oxidation, diffusion, deposition, etching, photolithography. Lecture and laboratory. Projects to design and simulate device fabrication sequence.
34	Development of a complete integrated microsystem, from functional defi nition to fi nal test. MEMS-based transducer design and electrical, mechanical and thermal limits. Design of MOS interface circuits. MEMS and MOS chip fabrication. Mask making, pattern transfer, oxidation, ion implantation and metallization. Packaging and testing challenges. Students work in interdisciplinary teams.
35	Design techniques for rapid implementations of very large-scale integrated (VLSI) circuits, MOS technology and logic. Structured design. Design rules, layout procedures. Design aids: layout, design rule checking, logic, and circuit simulation. Timing. Testability. Architectures for VLSI. Projects to develop and lay out circuits.
36	Materials for optoelectronics, optical processes in semiconductors, absorption and radiation, transition rates and carrier lifetime. Principles of LEDs, lasers, photodetectors, modulators and solar cells. Optoelectronic integrated circuits. Designs, demonstrations and projects related to optoelectronic device phenomena.
37	Fundamentals of electromagnetic wave propagation in the ionosphere, the troposphere, and near the Earth. Student teams will develop practical radio link designs and demonstrate critical technologies. Simple antennas, noise, diffraction, refraction, absorption, multi-path interference, and scattering are studied.
38	Introduction to photonics, opto-electronics, lasers and fi ber-optics. Topics include mirrors, interferometers, modulators and propagation in waveguides and fi bers. The second half treats photons in semiconductors, including semiconductor lasers, detectors and noise effects. System applications include fi ber lightwave systems, ultra-high-peak power lasers, and display technologies.
39	Basic physical optics treated from the viewpoint of Fourier analysis. Fouriertransform relations in optical systems. Theory of image formation and Fourier transformation by lenses. Frequency response of diffraction-limited and aberrated imaging systems. Coherent and incoherent light. Comparison of imagery with coherent and with incoherent light. Resolution limitations. Optical information processing, including spatial matched fi ltering.
40	Construction and design of lasers; gaussian beams; nonlinear optics; fi ber optics; detectors; dispersion; Fourier optics; spectroscopy. Project requires the design and set-up of a practical optical system.

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	Description
41	Computational methods for the recovery, representation, and application of visual information. Topics from image formation, binary images, digital geometry, similarity and dissimilarity detection, matching, curve and surface fi tting, constraint propagation relaxation labeling, stereo, shading texture, object representation and recognition, dynamic scene analysis, and knowledge based techniques. Hardware, software techniques.
42	Introduction to digital signal processing of continuous and discrete signals. The family of Fourier Transforms including the Discrete Fourier Transform (DFT). Development of the Fast Fourier Transform (FFT). Signal sampling and reconstruction. Design and analysis of digital fi lters. Correlation and spectral estimation. Laboratory experiences exercise and illustrate the concepts presented.
43	Architectures of single-chip DSP processors. Laboratory exercises using two state-of-the-art fi xedpoint processors; A/D and D/A conversion, digital waveform generators, and real-time FIR and IIR fi lters. Central to this course is a team project in real-time DSP design (including software and hardware).
44	Digital transmission techniques in data communications, with application to computer and space communications; design and detection of digital signals for low error rate; forward and feedback transmission techniques; matched fi lters; modems, block and convolutional coding; Viterbi decoding.
45	Measurement and analysis of biopotentials and biomedical transducer characteristics; electrical safety; applications of FETs, integrated circuits, operational amplifi ers for signal processing and computer interfacing; signal analysis and display on the laboratory minicomputer. Lectures and laboratory.
46	Basic techniques for analysis and design of controllers applicable in any industry (e.g. automotive, aerospace, semiconductor, bioengineering, power, etc.) are discussed. Both time- and frequency-domain methods are covered. Root locus, Nyquist stability criterion, and Bode plot-based techniques are used as tools for analysis and design.
47	Basic interdisciplinary concepts needed to implement a microprocessor based control system. Sensors and actuators. Quadrature decoding. Pulse width modulation. DC motors. Force feedback algorithms for human computer interaction. Real time operating systems. Networking. Use of MATLAB to model hybrid dynamical systems. Autocode generation for rapid prototyping. Lecture and laboratory.
48	Basic concepts of computer architecture and organization. Computer evolution. Design methodology. Performance evaluation. Elementary queueing models. CPU architecture. Introduction sets. ALU design. Hardware and microprogrammed control. Nanoprogramming. Memory hierarchies. Virtual memory. Cache design. Input-output architectures. Interrupts and DMA. I/O processors. Parallel processing. Pipelined processors. Multiprocessors.
49	Fundamental techniques for designing effi cient algorithms and basic mathematical methods for analyzing their performance. Paradigms for algorithm design: divide-and-conquer, greedy methods, graph search techniques, dynamic programming. Design of effi cient data structures and analysis of the running time and space requirements of algorithms in the worst and average cases.
50	Advanced design of logic circuits. Technology constraints. Theoretical foundations. Computer-aided design algorithms. Two-level and multilevel optimization of combinational circuits. Optimization of fi nite-state machines. High-level synthesis techniques: modeling, scheduling, and binding. Verifi cation and testing.
51	Pragmatic aspects of the production of software systems, dealing with structuring principles, design methodologies and informal analysis. Emphasis is given to development of large, complex software systems. A term project is usually required.

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	Description
52	Operating system design and implementation: multi-tasking; concurrency and synchronization; inter-process communication; deadlock; scheduling; resource allocation; memory and storage management; input-output; fi le systems; protection and security. Students write several substantial programs dealing with concurrency and synchronization in a multi-task environment, with file systems, and with memory management.
53	Introduction to compiling techniques including parsing algorithms, semantic processing and optimization. Students implement a compiler for a substantial programming language using a compiler generating system.
54	Concepts and methods for the design, creation, query and management of large enterprise databases. Functions and characteristics of the leading database management systems. Query languages such as SQL, forms, embedded SQL, and application development tools. Database design, integrity, normalization, access methods, query optimization, transaction management and concurrency control and recovery.
55	Design and use of databases in the Web context; data models, database design, replication issues, client/server systems, information retrieval, web server design; substantial project involving the development of a databasebacked web site.
56	Object-based requirement analysis and design concepts such as program abstraction, encapsulation, polymorphism, inheritance, generalization, and reusability. Object oriented system decomposition and class design. Use of an OO Modeling and design methodology such as UML or OMT. Implementation of a software system based on OO requirement and design analysis is required.
57	Computer graphics hardware, line drawing, rasterization, anti-aliasing, graphical user interface (GUI), affi ne geometry, projective geometry, geometric transformation, polygons, curves, splines, solid models, lighting and shading, image rendering, ray tracing, radiosity, hidden surface removal, texture mapping, animation, virtual reality, and scientifi c visualization.
58	Protocols and architectures of computer networks. Topics include client-server computing, socket programming, naming and addressing, media access protocols, routing and transport protocols, fl ow and congestion control, and other application-specifi c protocols. Emphasis is placed on understanding protocol design principles. Programming problems to explore design choices and actual implementation issues assigned.
59	Fundamental concepts of AI, organized around the task of building computational agents. Core topics include search, logic, representation and reasoning, automated planning, decision making under uncertainty, and machine learning.
60	Concepts and techniques for designing computer system user interfaces to be easy to learn and use, with an introduction to their implementation. Task analysis, design of functionality, display and interaction design, and usability evaluation. Interface programming using an object-oriented application framework. Fluency in a standard object-oriented programming language is assumed.
61	Concepts and methods for the design and development of computer games. Topics include: history of games, 2D graphics and animation, sprites, 3D animation, binary space partition trees, software engineering, game design, interactive fi ction, user interfaces, artifi cial intelligence, game SDK's, networking, multi-player games, game development environments, commercialization of software.
62	Design principles for multidisciplinary team projects, team strategies, entrepreneurial skills, ethics, social and environmental awareness, and life long learning. Each student must take (simultaneously) Tech Comm 496 (2 cr.) and one of the approved 400-level team project courses in computing (4 cr.).
63	Professional problem-solving methods developed through intensive group studies. Normally one signifi cant design project is chosen for entire class requiring multiple EECS disciplines and teams. Use of analytic, computer, design, and experimental techniques where applicable are used. Projects are often interdisciplinary allowing non-EECS seniors to also take the course (consult with instructor).
64	Topics of current interest selected by the faculty. Lecture, seminar or laboratory.

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	Description
65	Individual study of selected topics in Electrical Engineering and Computer Science. May include experimental investigation or library research. Primarily for undergraduates.
66	Students are introduced to the frontiers of System Science research. Sections 01, 02, and 03 are devoted, respectively, to Communications, Control, and Signal Processing. The tutorials are delivered by leaders of the respective research fi elds, invited from academia and industry. The presentations are self-contained and accessible to all graduate students in System Science.
67	Introduction to probability and random processes. Topics include probability axioms, sigma algebras, random vectors, expectation, probability distributions and densities, Poisson and Wiener processes, stationary processes, autocorrelation, spectral density, effects of fi ltering, linear least-squares estimation, and convergence of random sequences. A student may receive credit for only one: EECS 401 and EECS 501.
68	Correlations and spectra. Quadratic mean calculus, including stochastic integrals and representations, wide-sense stationary processes (fi ltering, white noise, sampling, time averages, moving averages, autoregression). Renewal and regenerative processes, Markov chains, random walk and run, branching processes, Markov jump processes, uniformization, reversibility, and queueing applications.
69	Introduction to numerical methods in electromagnetics including fi nite difference, fi nite element and integral equation methods for static, harmonic and time dependent fi elds; use of commercial software for analysis and design purposes; applications to open and shielded transmission lines, antennas, cavity resonances and scattering.
70	Theory and application of analytic methods for evaluating the performance and reliability of computing systems. Measures of performance, reliability, and performability. Reliability evaluation: classifi cation and representation of faults, stochastic process models, coherent systems. Performance evaluation: Markovian queueing models, networks of queues. Unifi ed performance-reliability evaluation.
71	Traffi c Models and their analysis in the context of ITS (Intelligent Transportation Systems). Those aspects of traffi c theory relevant to ITS are presented including traffi c fl ow and signalized intersections, with particular emphasis on the optimization via route guidance and signal control of large scale traffi c networks.
72	Topics include driver-highway interactions (traffi c modeling, analysis and simulation), driver-vehicle interactions (human factors), vehicle-highway interactions (computer/communications systems architecture), collision prevention, ITS technologies (in-vehicle electronic sensors, etc.), socioeconomic aspects (user acceptance and liability), and system integration (comprehensive modeling and competitive strategy).
73	Introduction and fundamentals of physical, optical and electrical properties of amorphous and microcrystalline semiconductor based devices: MIM structures, Schottky diodes, p-i-n junctions, heterojunctions, MIS structures, thin- fi lm transistors, solar cells, threshold and memory switching devices and large area x-ray radiation detectors.
74	Introduction and fundamentals to the passive, active, refl ective and emissive fl at panel display technologies. This course will discuss the physics, operating principles, properties and technology of the fl at panel displays.
75	Advanced micro electro mechanical systems (MEMS) devices and technologies. Transduction techniques, including piezoelectric, electrothermal, and resonant techniques. Chemical, gas, and biological sensors, microfl uidic and biomedical devices. Micromachining technologies such as laser machining and microdrilling, EDM, materials such as SiC and diamond. Sensor and actuator analysis and design through CAD.
76	Review of interface electronics for sense and drive and their infl uence on device performance, interface standards, MEMS and circuit noise sources, packaging and assembly techniques, testing and calibration approaches, and communication in integrated microsystems. Applications, including RF MEMS, optical MEMS, bioMEMS, and microfl uidics. Design project using CAD and report preparation.

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	Description
77	Principles of modern medical imaging systems. For each modality the basic physics is described, leading to a systems model of the imager. Fundamental similarities between the imaging equations of different modalities will be stressed. Modalities covered include radiography, x-ray computed tomography (CT), NMR imaging (MRI) and real-time ultra-sound.
78	Plasma physics applied to electrical gas discharges used for material processing. Gas kinetics; atomic collisions; transport coeffi cients; drift and diffusion; sheaths; Boltzmann distribution function calculation; plasma simulation; plasma diagnostics by particle probes, spectroscopy, and electromagnetic waves; analysis of commonly used plasma tools for materials processing.
79	General principles of magnetohydrodynamics; theory of the expanding atmospheres; properties of solar wind, interaction of solar wind with the magnetosphere of the Earth and other planets; bow shock and magnetotail, trapped particles, auroras.
80	Laboratory techniques for plasma ionization and diagnosis relevant to plasma processing, propulsion, vacuum electronics, and fusion. Plasma generation includes: high voltage-DC, radio frequency, and electron beam sustained discharges. Diagnostics include: Langmuir probes, microwave cavity perturbation, microwave interferometry, laser schlieren, and optical emission spectroscopy. Plasma parameters measured are: electron/ion density and electron temperature.
81	The course discusses in detail the theory behind important semiconductorbased experiments such as Hall effect and Hall mobility measurement; velocity- fi eld measurement; photoluminescence; gain; pump-probe studies; pressure and strain-dependent studies. Theory will cover: Bandstructure in quantum wells; effect of strain on bandstructure; transport theory; Monte Carlo methods for high fi eld transport; excitons, optical absorption, luminescence and gain.
82	Detailed theory of high-speed digital and high-frequency analog transistors. Carrier injection and control mechanisms. Limits to miniaturization of conventional transistor concepts. Novel submicron transistors including MESFET, heterojunction and quasi-ballistic transistor concepts.
83	Review of integrated circuit fabrication technologies and BJT and MOS transistor models. Detailed analysis and design of analog integrated circuits, including power amplifi ers, voltage references, voltage regulators, rectifi ers, oscillators, multipliers, mixers, phase detectors, and phase-locked loops. Design projects. Lectures and discussion.
84	Integrated circuit fabrication overview, relationships between processing choices and device performance characteristics. Long-channel device I-V review, short-channel MOSFET I-V characteristics including velocity saturation, mobility degradation, hot carriers, gate depletion. MOS device scaling strategies, silicon-on-insulator, lightly-doped drain structures, on-chip interconnect parasitics and performance. Major CMOS scaling challenges. Process and circuit simulation.
85	Physical and electrical properties of III-V materials, epitaxy and ion-implantation, GaAs and InP based devices (MESFETs, HEMTs varactors) and Microwave Monolithic Integrated Circuits (MMICs). Cleaning, Photolithography, metal and dielectric deposition, wet and dry etching. Device isolation, ohmic and Schottky contacts, dielectrics, passive component technology, interconnects, via holes, dicing and mounting. Study of the above processes by DC characterization.
86	General properties and design of linear and nonlinear solid state microwave circuits including: amplifi er gain blocks, low-noise, broadband and power amplifi ers, oscillators, mixer and multiplier circuits, packaging, system implementation for wireless communication.
87	Models for devices (BJTs, FETs, and integrated circuits), with primary emphasis on large-signal dynamic charge-control models. Mathematics and physics fundamentals for measurement concepts and methods. Mathematical and computer analysis and design of high-speed dynamic circuits. Dynamic circuit functional blocks, level detection/comparison circuits; sweep/ramp, multivibrator, and logic gate circuits.

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	Description
88	Theory of circuit layout partitioning and placement algorithms. Routing algorithms, parallel design automation on shared memory and distributed memory multi-processors, simulated annealing and other optimization techniques and their applications in CAD, layout transformation and compaction, fault-repair algorithms for RAMs and PLAs hardware synthesis from behavioral modeling, artificial intelligence-based CAD.
89	Theoretical analysis of the chemistry and physics of process technologies used in micro-electronics fabrication. Topics include: semiconductor growth, material characterization, lithography tools, photo-resist models, thin fi lm deposition, chemical etching, plasma etching, electrical contact formation, microstructure processing, and process modeling.
90	Optical processes in semiconductors, spontaneous emission, absorption gain, stimulated emission. Principles of light-emitting diodes, including transient effects, spectral and spatial radiation fi elds. Principles of semiconducting lasers; gain-current relationships, radiation fi elds, optical confi nement and transient effects.
91	Maxwell's equations, constitutive relations and boundary conditions. Potentials and the representation of electromagnetic fi elds. Uniqueness, duality, equivalence, reciprocity and Babinet's theorems. Plane, cylindrical, and spherical waves. Waveguides and elementary antennas. The limiting case of electro- and magneto-statics.
92	Theory of transmitting and receiving antennas. Reciprocity. Wire antennas: dipoles, loops and traveling-wave antennas. Analysis and synthesis of linear arrays. Phased arrays. Input impedance and method of moments. Mutual impedance. Aperture antennas: slot, Babinet's principle. Microstrip antennas. Horns, refl ector and lens antennas.
93	Radiative transfer theory: blackbody radiation; microwave radiometry; atmospheric propagation and emission; radiometer receivers; surface and volume scattering and emission; applications to meteorology, oceanography, and hydrology.
94	Advanced topics in microwave measurements: power spectrum and noise measurement, introduction to state-of-the-art microwave test equipment, methods for measuring the dielectric constant of materials, polarimetric radar cross section measurements, near fi eld antenna pattern measurements, electromagnetic emission measurement (EM compatibility). Followed by a project that will include design, analysis, and construction of a microwave subsystem.
95	Theory and design of passive and active microwave components and monolithic integrated circuits including: microstrip, lumped inductors and capacitors, GaAs FETs, varactor and mixer diodes, monolithic phase shifters, attenuators, amplifi ers and oscillators. Experimental characterization of the above components using network analyzer, spectrum analyzer, power and noise meters. Lecture and laboratory.
96	Theory of image formation with holography; applications of holography; white light interferometry; techniques for optical digital computing; special topics of current research interest.
97	Applications of random variables to optics; statistical properties of light waves. Coherence theory, spatial and temporal. Information retrieval; imaging through inhomogeneous media; noise processes in imaging and interferometric systems.
98	Theory of electromagnetic, physical, and geometrical optics. Classical theory of dispersion. Linear response, Kramers-Kronig relations, and pulse propagation. Light scattering. Geometrical optics and propagation in inhomogeneous media. Dielectric waveguides. Interferometry and theory of coherence. Diffraction, Fresnel and Fraunhofer. Gaussian beams and ABCD law.
99	Propagation of laser beams: Gaussian wave optics and the ABCD law. Manipulation of light by electrical, acoustical waves; crystal properties and the dielectric tensor; electro-optic, acousto-optic effects and devices. Introduction to nonlinear optics; harmonic generation, optical rectifi cation, four-wave mixing, self-focusing, and self-phase modulation.

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	Description
100	Complete study of laser operation: the atom-fi eld interaction; homogeneous and inhomogeneous broadening mechanisms; atomic rate equations; gain and saturation; laser oscillation; laser resonators, modes, and cavity equations; cavity modes; laser dynamics, Q-switching and modelocking. Special topics such as femto-seconds lasers and ultrahigh power lasers.
101	Introduction to nonrelativistic quantum mechanics. Summary of classical mechanics, postulates of quantum mechanics and operator formalism, stationary state problems (including quantum wells, harmonic oscillator, angular momentum theory and spin, atoms and molecules, band theory in solids), time evolution, approximation methods for time independent and time dependent interactions including electromagnetic interactions, scattering.
102	Continuation of nonrelativistic quantum mechanics. Advanced angular momentum theory, second quantization, non-relativistic quantum electrodynamics, advanced scattering theory, density matrix formalism, reservoir theory.
103	Details of image formation theory, including the consideration of dynamic image sequences. The theoretical frameworks for edge detection, feature extraction, and surface description are presented. The relationship between image formation and object features is examined in detail. Programming required.
104	Techniques and principles for developing application software based on explicit representation and manipulation of domain knowledge, as applied to areas such as pattern matching, problem-solving, automated planning, and naturallanguage processing. Discussion of major programming approaches used in the design and development of knowledge-based systems.
105	Survey of recent research on learning in artifi cial intelligence systems. Topics include learning based on examples, instructions, analogy, discovery, experimentation, observation, problem-solving and explanation. The cognitive aspects of learning will also be studied.
106	Propagation of ultrashort optical pulses in linear and nonlinear media, and through dispersive optical elements. Laser mode-locking and ultrashort pulse generation. Chirped-pulse amplifi cation. Experimental techniques for high time resolution. Ultrafast Optoelectronics. Survey of ultrafast high fi eld interactions.
107	Introduction to the design and analysis of automated commerce systems, from both a technological and social perspective. Infrastructure supporting search for commerce opportunities, negotiating terms of trade, and executing transactions. Issues of security, privacy, incentives, and strategy.
108	The concepts of source, channel, rate of transmission of information. Entropy and mutual information. The noiseless coding theorem. Noisy channels; the coding theorem for fi nite state zero memory channels. Channel capacity. Error bounds. Parity check codes. Source encoding.
109	Review of DTFT and digital fi ltering. Multirate fi ltering. Filter banks and subband decomposition of signals. Multiresolution subspaces. Wavelet scaling and basis functions and their design: Haar, Littlewood-Paley, Daubechies, Battle- Lemarie. Denoising and compression applications. Spectrogram, Wigner-Ville, Cohen's class of time-frequency distributions and their applications.
110	Principles of fi ber optical communications and networks. Point-to-point systems and shared medium networks. Fiber propagation including attenuation, dispersion and nonlinearities. Topics covered include erbium-doped amplifi ers, Bragg and long period gratings, fi ber transmission based on solitons and nonreturn- to-zero, and time- and wavelength-division-multiplexed networks.
111	Digital transmission of information across discrete and analog channels. Sampling; quantization; noiseless source codes for data compression: Huffman's algorithm and entropy; block and convolutional channel codes for error correction; channel capacity; digital modulation methods: PSK, MSK, FSK, QAM; matched fi lter receivers. Performance analysis: power, bandwidth, data rate, and error probability.

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	Description
112	Theory of digital modulation and coding. Optimum receivers in Gaussian noise. Signal space and decision theory. Signal design. Bandwidth and dimensionality. Fundamental limits in coding and modulation. Capacity and cutoff rate. Block, convolutional and trellis coding. Continuous phase modulation. Filtered channels and intersymbol interference. Equalization. Spread-spectrum. Fading channels. Current topics.
113	Theory and application of digital image processing. Random fi eld models of images. Sampling, quantization, image compression, enhancement, restoration, segmentation, shape description, reconstruction of pictures from their projections, pattern recognition. Applications include biomedical images, timevarying imagery, robotics, and optics.
114	System architectures. Data link control: error correction, protocol analysis, framing. Message delay: Markov processes, queuing, delays in statistical multiplexing, multiple users with reservations, limited service, priorities. Network delay: Kleinrock independence, reversibility, traffi c fl ows, throughput analysis, Jackson networks. Multiple access networks: ALOHA and splitting protocols, carrier sensing, multi-access reservations.
115	Analysis and optimization of controlled stochastic systems. Models: linear and nonlinear stochastic controlled systems, controlled Markov chains. Optimization of systems described by Markov processes; dynamic programming under perfect and imperfect information, fi nite and infi nite horizons. System identifi cation: off-line, recursive. Stochastic adaptive control: Markov chains, self-tuning regulators, bandit problems.
116	Estimators of second order properties of random processes: nonparametric and model-based techniques of spectral estimation, characterization of output statistics for nonlinear systems, time-frequency representations. Performance evaluation using asymptotic techniques and Monte Carlo simulation. Applications include speech processing, signal extrapolation, multidimensional spectral estimation, and beamforming.
117	Linear spaces and linear operators. Bases, subspaces, eigenvalues and eigenvectors, canonical forms. Linear differential and difference equations. Mathematical representations: state equations, transfer functions, impulse response, matrix fraction and polynomial descriptions. System-theoretic concepts: causality, controllability, observability, realizations, canonical decomposition, stability.
118	Sampling and data reconstruction. Z-transforms and state variable descriptions of discrete-time systems. Modeling and identifi cation. Analysis and design using root locus, frequency response, and state space techniques. Linear quadratic optimal control and state estimation. Quantization and other nonlinearities. Computer simulations and laboratory implementation of realtime control systems.
119	Introduction to the analysis and design of nonlinear systems and nonlinear control systems. Stability analysis using Liapunov, input-output and asymptotic methods. Design of stabilizing controllers using a variety of methods: linearization, absolute stability theory, vibrational control, sliding modes and feedback linearization.
120	Principles of estimation, linear fi ltering and detection. Estimation: linear and nonlinear minimum mean squared error estimation, and other strategies. Linear fi ltering: Wiener and Kalman fi ltering. Detection: simple, composite, binary and multiple hypotheses. Neyman-Pearson and Bayesian approaches.
121	Control design concepts for linear multivariable systems. Review of single variable systems and extensions to multivariable systems. Purpose of feedback. Sensitivity, robustness, and design tradeoffs. Design formulations using both frequency domain and state space descriptions. Pole placement/observer design. Linear quadratic Gaussian based design methods. Design problems unique to multivariable systems.
122	Introduction to robots considered as electro-mechanical computational systems performing work on the physical world. Data structures representing kinematics and dynamics of rigid body motions and forces and controllers for achieving them. Emphasis on building and programming real robotic systems and on representing the work they are to perform.

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	Description
123	Architectures for explicit parallelism. Multithreaded processors, small- and large-scale multiprocessor systems. Shared-memory coherence and consistency. Effect of architecture on communication latency, bandwidth, and overhead. Latency tolerance techniques. Interconnection networks. Case studies. Term projects.
124	Principles of real-time computing based on high performance, ultra reliability and environmental interface. Architectures, algorithms, operating systems and applications that deal with time as the most important resource. Real-time scheduling, communications and performance evaluation.
125	Graduate-level introduction to the foundations of high performance microprocessor implementation. Problems involving instruction supply, data supply, and instruction processing. Compile-time vs. run-time tradeoffs. Aggressive branch prediction. Wide-issue processors, in-order vs. out-of-order execution, instruction retirement. Case studies taken from current microprocessors.
126	Fundamentals of the theory of computation and complexity theory. Computability, undecidability, and logic. Relations between complexity classes, NPcompleteness, P-completeness, and randomized computation. Applications in selected areas such as cryptography, logic programming, theorem proving, approximation of optimization problems, or parallel computing.
127	A rigorous introduction to the design of cryptosystems and to cryptanalysis. Topics include cryptanalysis of classical cryptosystems; theoretical analysis of one-way functions; DES and differential cryptanalysis; the RSA cryptosystem; ElGamal, elliptic, hyperelliptic and hidden mononomial cryptosystems; attacks on signature schemes, identifi cation schemes and authentication codes; secret sharing; and zero knowledge.
128	An introduction to models and methods used in the analysis and design of reliable hardware systems, software systems and computing systems. Aspects of reliability considered include fault tolerance, fault detection and diagnosis, reconfi guration, design verifi cation and testing, and reliability evaluation.
129	Design specifi cation vs. implementation. Design errors. Functional and temporal modeling of digital systems. Simulation vs. symbolic verifi cation techniques. Functional verifi cation of combinational and sequential circuits. Topological and functional path delays; path sensitization. Timing verifi cation of combinational and sequential circuits. Clock schedule optimization.
130	Overview of fault-tolerant computing. Fault sources and models. Testing process. Combinational circuit testing. D-Algorithm and PODEM. Sequential circuit testing. Checking experiments. RAM and microprocessor testing. Fault simulation. Design for testability. Testability measures. Self-testing circuits and systems.
131	Fundamental areas of software engineering including life-cycle-paradigms, metrics, and tools. Information hiding architecture, modular languages, design methodologies, incremental programming, and very high level languages.
132	Course discusses advanced topics and research issues in operating systems. Topics will be drawn from a variety of operating systems areas such as distributed systems and languages, networking, security, and protection, realtime systems, modeling and analysis, etc.
133	In-depth study of compiler backend design for high-performance architectures. Topics include control-fl ow and data-fl ow analysis, optimization, instruction scheduling, register allocation. Advanced topics include memory hierarchy management, instruction-level parallelism, predicated and speculative execution. The class focus is processor-specifi c compilation techniques, thus familiarity with both computer architecture and compilers is recommended.
134	Survey of advanced topics in database systems. Distributed databases, query processing, transaction processing. Effects of data models: object-oriented and deductive databases; architectures: main-memory and parallel repositories; distributed organizations: client-server and heterogeneous systems. Basic data management for emerging areas: internet applications, OLAP, data mining. Case studies of existing systems. Group projects.

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	Description
135	Web-related client-server protocols and performance issues; web proxies; web caching and prefetching; dynamic web content; server-side web applications support; scalable web servers; security topics such as user authentication, secure sockets layer and secure HTTP; electronic payment systems; webbased virtual communities; information discovery.
136	Design of algorithms for nonnumeric problems involving sorting, searching, scheduling, graph theory, and geometry. Design techniques such as approximation, branch-and-bound, divide-and-conquer, dynamic programming, greed, and randomization applied to polynomial and NP-hard problems. Analysis of time and space utilization.
137	The development of programs for parallel computers. Basic concepts such as speedup, load balancing, latency, system taxonomies. Design of algorithms for idealized models. Programming on parallel systems such as shared or distributed memory machines, networks. Performance analysis. Course includes a substantial term project.
138	Advanced topics and research issues in computer networks. Topics include routing protocols, multicast delivery, congestion control, quality of service support, network security, pricing and accounting, and wireless access and mobile networking. Emphasis is placed on performance trade-offs in protocol and architecture designs. Readings assigned from research publications. A course project allows in-depth exploration of topics of interest.
139	Principles and practice of distributed system design. Computations, consistency semantics, and failure models. Programming paradigms including group communication, RPC, distributed shared memory, and distributed objects. Operating system kernel support; distributed system services including replication, caching, fi le system management, naming, clock synchronization, and multicast communication. Case studies.
140	Advanced topics in artifi cial intelligence. Issues in knowledge representation, knowledge-based systems, problem solving, planning and other topics will be discussed. Students will work on several projects.
141	Programs and automata that ?learn? by adapting to their environment; programs that utilize genetic algorithms for learning. Samuel's strategies, realistic neural networks, connectionist systems, classifi er systems, and related models of cognition. Artifi cial intelligence systems, such as NETL and SOAR, are examined for their impact upon machine learning and cognitive science.
142	A survey of syntactic and semantic theories for natural language processing, including unifi cation-based grammars, methods of parsing, and a wide range of semantic theories from artifi cial intelligence as well as from philosophy of language. Programming will be optional, though a project will normally be required.
143	To be elected by EECS students pursuing the Master of Engineering degree. Students are expected to work in project teams, May be taken more than once up to a total of 6 credit hours.
144	A survey of techniques used in language studies and information processing. Students will learn how to explore and analyze textual data in the context of Web-based information retrieval systems. At the conclusion of the course, students will be able to work as information designers and analysts.
145	Topics of current interest in electrical engineering and computer science. Lectures, seminar, or laboratory. Can be taken more than once for credit.
146	Individual study of selected advanced topics in electrical engineering and computer science. May include experimental work or reading. Primarily for graduate students. To be graded on satisfactory/unsatisfactory basis ONLY.
147	Introduction to the description and analysis of systems using function analytic methods. Metric spaces, normed linear spaces, Hilbert spaces, resolution spaces. Emphasis on using these concepts in systems problems.
148	Fundamental principles and design of integrated solid-state sensors and sensing systems. Micromachining and wafer bonding. Microstructures for the measurement of visible and infrared radiation, pressure, acceleration, temperature, gas purity, an ion concentrations. Merged process technologies for sensors and circuits. Data acquisitions circuits, microactuators and integrated microsystems.

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	Description
149	Advanced very large scale integrated (VLSI) circuit design. Design methodologies (architectural simulation, hardware description language design entry, silicon compilation, and verifi cation), microarchitectures, interconnect, packaging, noise sources, circuit techniques, design for testability, design rules, VLSI technologies (silicon and GaAs), and yield. Projects in chip design.
150	Boundary conditions, fi eld representations. Low and high frequency scattering. Scattering by half plane (Wiener-Hopf method) and wedge (Maliuzhinets method); edge diffraction. Scattering by a cylinder and sphere: Watson transformation, Airy and Fock functions, creeping waves. Geometrical and physical theories of diffraction.
151	Radar equation; noise statistics; resolution techniques; calibration; synthetic aperture radar; scatterometers; scattering models; surface and volume scattering; land and oceanographic applications.
152	Numerical techniques for antennas and scattering; integral representation: solutions of integral equations: method of moments, Galerkin's technique, conjugate gradient FFT; fi nite element methods for 2-D and 3-D simulations; hybrid fi nite element/boundary integral methods; applications: wire, patch and planar arrays; scattering composite structures.
153	Formalism of wave propagation in nonlinear media; susceptibility tensor; second harmonic generation and three-wave mixing; phase matching; third order nonlinearities and four-wave mixing processes; stimulated Raman and Brillouin scattering. Special topics: nonlinear optics in fi bers, including solitons and self-phase modulation.
154	The atom-fi eld interaction; density matrix; quantum theory of radiation including spontaneous emission; optical Bloch equations and theory of resonance fl uorescence; coherent pulse propagation; dressed atoms and squeezed states; special topics in nonlinear optics.
155	This course will review computational models of human cognitive processes with four goals in mind: (1) to learn about the wide variety of approaches to cognitive modeling (e.g., self-organizing nets, multi-layer nets, and backpropogation, production systems, ACT*, EPIC, Soar?) and the advantages and disadvantages of each, (2) to study some of the most important cognitive models of specifi c domains (e.g., dual task performance, reasoning, explicit learning, working memory?.), (3) to evaluate when cognitive modeling is an appropriate and useful research strategy, and (4) to give students an opportunity to gain hands-on experience in implementing their own cognitive models. Students will be expected to take turns in leading discussion of specifi c papers and to work in groups in implementing a computational model.
156	This course will examine computational models of human cognitive processes. Course goals include learning about important computational models of specifi c cognitive domains and evaluating the appropriateness and utility of different computational approaches to substantive problems in cognition.
157	The theory of channel coding for reliable communication and computer memories. Error correcting codes; linear, cyclic and convolutional codes; encoding and decoding algorithms; performance evaluation of codes on a variety of channels.
158	Introduction to a variety of source coding techniques such as quantization, block quantization; and differential, predictive, transform and tree coding. Introduction to rate-distortion theory. Applications include speech and image coding.
159	Introduction to abstract algebra with applications to problems in signal processing. Fast algorithms for short convolutions and the discrete Fourier transform; number theoretic transforms; multidimensional transforms and convolutions; fi lter architectures.
160	Theory and applications of adaptive fi ltering in systems and signal processing. Iterative methods of optimization and their convergence properties: transversal fi lters; LMS (gradient) algorithms. Adaptive Kalman fi ltering and least-squares algorithms. Specialized structures for implementation: e.g., least-squares lattice fi lters, systolic arrays. Applications to detection, noise cancelling, speech processing, and beam forming.

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	Description
161	Modeling, analysis, and control of discrete event systems; untimed (logical) and timed models considered. Defi ning characteristics of discrete event systems. Logical models: languages, automata, and Petri nets. Analysis: safety, blocking, state estimation and diagnostics. Supervisory control: controllability, nonblocking and nonconfl icting languages, observability and co-observability. Timed models: timed automata and timed Petri nets. Analysis using diod algebras. Control of Petri nets. Introduction to stochastic models.
162	Geometric and algebraic approaches to the analysis and design of nonlinear control systems. Nonlinear controllability and observability, feedback stabilization and linearization, asymptotic observers, tracking problems, trajectory generation, zero dynamics and inverse systems, singular perturbations, and vibrational control.
163	Current topics of interest in computer architecture. This course may be repeated for credit.
164	Current topics of interest in theoretical computer science. This course can be repeated for credit.
165	Current topics of interest in software systems. This course can be repeated for credit more than once.
166	Research issues in database systems chosen for in-depth study. Selected topics such as spatial, temporal, or real-time databases; data mining, data warehousing, or other emerging applications. Readings from recent research papers. Group projects.
167	Current topics of interest in artifi cial intelligence. This course can be repeated for credit more than once.
168	Consideration of adaptively and biologically oriented theories of human behavior. Emphasis on both the potential breadth of application and intuitive reasonableness of various models. There is a bias toward large theories and small simulations.
169	To be elected by EE and EES students pursuing the master's thesis option. May be taken more than once up to a total of 6 credit hours. To be graded on a satisfactory/unsatisfactory basis ONLY.
170	Students working under the supervision of a faculty member plan and execute a research project. A formal report must be submitted. May be taken for credit more than once up to a total of 6 credit hours. To be graded satisfactory/ unsatisfactory ONLY.
171	null_no_value
172	Special topics of current interest in solid-state devices, integrated circuits, microwave devices, quantum devices, noise, plasmas. This course may be taken for credit more than once.
173	null_no_value
174	Study and discussion of various topics related to high frequency applications in space exploration. Topics will be chosen from the following areas: planetary atmospheres and remote sensing, antennas, active and passive circuits, space instrumentation.
175	Key topics of current research interest in ultrafast phenomena, short wavelength lasers, atomic traps, integrated optics, nonlinear optics and spectroscopy. This course may be taken for credit more than once under different instructors.
176	null_no_value
177	null_no_value
178	null_no_value
179	Advanced topics on stochastic systems such as stochastic calculus, nonlinear fi ltering, stochastic adaptive control, decentralized control, and queuing networks.
180	null_no_value
181	Advanced overviews of research, industrial and governmental projects not covered by the optics curriculum. Recent advances on important topics presented by renowned speakers in areas like hyperspectral imaging, laser cooling, biological manipulation, displays, laser metrology, holography and astrophysical instrumentation plus an annual site tour of local industrial optics facilities.
182	Advanced graduate seminar devoted to discussing current research topics in areas of solid-state electronics. Specifi c topics vary each time the course is offered. Course may be elected more than once.

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	Description
183	Advanced graduate seminar devoted to discussing current research papers in artifi cial intelligence. The specifi c topics vary each time the course is offered.
184	Dissertation work by doctoral student not yet admitted to status as candidate. The defense of the dissertation, that is, the fi nal oral examination, must be held under a full-term candidacy enrollment.
185	Election for dissertation work by a doctoral student who has been admitted to candidate status. The defense of the dissertation, that is, the fi nal oral examination, must be held under a full-term candidacy enrollment.

Table 21: Arizona State University Courses (IConcept ArizonaStateCSCourse)

	CourseNumber	Title	CreditHours	...
0	100	Principles of Programming with C++	3	...
1	110	Principles of Programming with Java	3	...
2	120	Digital Design Fundamentals	3	...
3	180	Computer Literacy	3	...
4	181	Applied Problem Solving with Visual BASIC	3	...
5	185	Internet and the World Wide Web	3	...
6	194	Introduction to Engineering Design	null_no_value	...
7	200	Concepts of Computer Science	3	...
8	210	Object-Oriented Design and Data Structures	3	...
9	225	Assembly Language Programming and Microprocessors (Motorola)	4	...
10	226	Assembly Language Programming and Microprocessors (Intel)	4	...
11	240	Introduction to Programming Languages	3	...
12	300	Intermediate Engineering Design	3	...
13	310	Data Structures and Algorithms	3	...
14	330	Computer Organization and Architecture	3	...
15	340	Principles of Programming Languages	3	...
16	355	Introduction to Theoretical Computer Science	3	...
17	360	Introduction to Software Engineering	3	...
18	408	Multimedia Information Systems	3	...
19	412	Database Management	3	...
20	420	Computer Architecture I	3	...
21	421	Microprocessor System Design I	4	...
22	422	Microprocessor System Design II	4	...
23	423	Microcomputer System Hardware	3	...
24	428	Computer-Aided Processes	3	...
25	430	Operating Systems	3	...
26	432	Operating System Internals	3	...
27	434	Computer Networks	3	...
28	438	Systems Programming	3	...
29	440	Compiler Construction I	3	...
30	445	Distributed Computing with Java and CORBA	3	...
31	446	Client-Server User Interfaces	3	...
32	450	Design and Analysis of Algorithms	3	...
33	457	Theory of Formal Languages	3	...

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	CourseNumber	Title	CreditHours	...
34	459	Logic for Computing Scientists	3	...
35	460	Software Analysis and Design	3	...
36	461	Software Engineering Project I	3	...
37	462	Software Engineering Project II	3	...
38	470	Computer Graphics	3	...
39	471	Introduction to Artificial Intelligence	3	...
40	473	Nonprocedural Programming Languages	3	...
41	476	Introduction to Natural Language Processing	3	...
42	477	Introduction to Computer-Aided Geometric Design	3	...
43	494	Advanced Database Concepts	3	...
44	494	Building and programming mobile robots	3	...
45	494	Information Retrieval, Mining and Integration on the Internet	3	...
46	494	Principles of Information Engineering	3	...
47	494/598	Wireless Sensor Networks	3	...
48	494	Real-Time Embedded Systems	3	...
49	507	Virtual Reality Systems	3	...
50	508	Digital Image Processing	3	...
51	510	Database Management System Implementation	3	...
52	512	Distributed Database Systems	3	...
53	513	Rules inDatabase Systems	3	...
54	514	Object-Oriented Database Systems	3	...
55	515	Multimedia and Web Databases	3	...
56	517	Hardware Design Languages	3	...
57	518	Synthesis with Hardware Design Languages	3	...
58	520	Computer Architecture II	3	...
59	521	Microprocessor Applications	4	...
60	523	Microcomputer Systems Software	3	...
61	526	Parallel Processing	3	...
62	530	Operating System Case Study	3	...
63	531	Distributed and Multiprocessor Operating Systems	3	...
64	532	Advanced Operating System Internals	3	...
65	534	Advanced Computer Networks	3	...
66	536	Advanced Operating Systems	3	...
67	537	ATM Networks	3	...
68	539	Applied Cryptography	3	...
69	540	Compiler Construction II	3	...
70	545	Programming Language Design	3	...
71	550	Combinatorial Algorithms and Intractability	3	...
72	555	Theory of Computation	3	...
73	556	Expert Systems	3	...
74	562	Software Process Automation	3	...
75	563	Software Requirements and Specification	3	...
76	564	Software Design	3	...
77	565	Software Verification, Validation and Testing	3	...
78	566	Software Project, Process and Quality Management	3	...
79	570	Advanced Computer Graphics I	3	...

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	CourseNumber	Title	CreditHours	...
80	571	Artificial Intelligence	3	...
81	573	Advanced Computer Graphics II	3	...
82	574	Planning and Learning Methods in AI	3	...
83	575	Decision-Making Strategies in AI	3	...
84	576	Topics in Natural Language Processing	3	...
85	577	Advanced Computer-Aided Geometric Design I	3	...
86	578	Advanced Computer-Aided Geometric Design II	3	...
87	579	NURBs: Nonuniform Rational B-Splines	3	...
88	591	Advanced Topics on Parallel and Distributed Computing	3	...
89	591	Autonomous Agents: theory and practice	3	...
90	591	Computational Algorithms for Systems Biology	3	...
91	591	Computational Molecular Biology	3	...
92	591	Data Mining	3	...
93	591	Hardware-Software Co-design	3	...
94	591	Image Processing-II Digital Video processing	3	...
95	591	Mobile Ad Hoc Networking Computing	3	...
96	591	Mobile Computing	3	...
97	591	Object Oriented Modeling Simulation	3	...
98	591	Practical Operating System Internals	3	...
99	591	Randomized and Approximation Algorithms	3	...
100	591	Semantic Web Mining	3	...

Table 21 – Continued

	MoreInfoURL	DescriptionText	...
0	null_no_value	Principles of problem solving using C++, algorithm design, structured programming, fundamental algorithms and techniques, and computer systems concepts	...
1	http://www.eas.asu.edu/~cse110	Concepts of problem solving using Java, algorithm design, structured programming, fundamental algorithms and techniques, and computer systems concepts	...
2	http://www.eas.asu.edu/~cse120	Number systems, conversion methods, binary and complement arithmetic, boolean and switching algebra, circuit minimization. ROMs, PLAs, flipflops, synchronous sequential circuits, and register transfer design	...
3	http://www.eas.asu.edu/~cse180	Introduction to general problem-solving approaches using widely available software tools such as database packages, word processors, spreadsheets, and report generators	...
4	http://www.eas.asu.edu/~cse181	Introduction to systematic definition of problems, solution formulation, and method validation. Computer solution using Visual BASIC required for projects	...
5	http://www.eas.asu.edu/~cse185	Fundamental Internet concepts. World Wide Web browsing, searching, publishing, advanced Internet productivity tools	...
6	http://www.eas.asu.edu/~hasancam/courses/Spring-2002/ece194/ece194.html	null_no_value	...

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	MoreInfoURL	DescriptionText	...
7	http://www.eas.asu.edu/~cse200/	Overview of algorithms, architecture, languages, computer systems, theory. Problem solving by programming with a high-level language (Java or another)	...
8	http://www.eas.asu.edu/~cse210/	Object Oriented Design, Static and Dynamic Data Structures (Strings, Stacks, Queues, Binary Trees), Recursion, Searching and Sorting, Professional Responsibility	...
9	null_no_value	Assembly language programming, including input/output programming and exception/interrupt handling. Register-level computer organization, I/O interfaces, assemblers, and linkers. Motorola-based assignments	...
10	http://www.eas.asu.edu/~sserc/226/	CPU/memory/peripheral device interfaces and programming. System buses, interrupts, serial and parallel I/O, DMA, coprocessors. Intel-based assignments	...
11	http://www.eas.asu.edu/~cse240/	Introduces the procedural (C++), applicative (LISP), and declarative (Prolog) languages	...
12	http://www.eas.asu.edu/~ece300/	null_no_value	...
13	http://www.eas.asu.edu/~cse310/	Advanced data structures and algorithms, including stacks, queues, trees (B, B+, AVL), and graphs. Searching for graphs, hashing and external sorting	...
14	http://www.eas.asu.edu/~cse330/	Instruction set architecture, processor performance and design; datapath, control (hardwired, microprogrammed), pipelining, input/output. Memory organization with cache, virtual memory	...
15	http://www.eas.asu.edu/~cse340/	Introduction to language design and implementation. Parallel, machine dependent and declarative language features; type theory; specification, recognition, translation, run-time management	...
16	http://www.eas.asu.edu/~cse355/	Introduction to formal language theory and automata, Turing machines, decidability/undecidability, recursive function theory, and introduction to complexity theory	...
17	null_no_value	Software life cycle models; Project management, team development, environments and methodologies; software architectures; quality assurance and standards; legal, ethical issues	...
18	http://www.eas.asu.edu/~cse408/	Design, use, and applications of multimedia systems. An introduction to acquisition, compression, storage, retrieval, and presentation of data from different media such as images, text, voice, and alphanumeric	...
19	http://www.eas.asu.edu/~cse412/	Introduction to DBMS concepts. Data models and languages. Relational database theory. Database security/ integrity and concurrency	...
20	null_no_value	Computer architecture. Performance versus cost trade-offs. Instruction set design. Basic processor implementation and pipelining	...
21	http://www.eas.asu.edu/~cse421/	Assembly-language programming and logical hardware design of systems using 8-bit microprocessors and micro-controllers. Fundamental concepts of digital system design. Reliability and social, legal implications	...
22	null_no_value	Design of microcomputer systems using contemporary logic and microcomputer system components	...

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	MoreInfoURL	DescriptionText	...
23	null_no_value	Information and techniques presented in CSE 422 are used to develop the hardware design of a microprocessor, multiprogramming, microprocessor-based system	...
24	null_no_value	Hardware and software considerations for computerized manufacturing systems. Specific concentration on automatic inspection, numerical control, robotics, and integrated manufacturing systems	...
25	http://www.eas.asu.edu/~cse430/	Operating system structure and services, processor scheduling, concurrent processes, synchronization techniques, memory management, virtual memory, input/output, storage management, file systems	...
26	http://www.eas.asu.edu/~cse432/	IPC, exception and interrupt processing, memory and thread management, user-level device drivers, and OS servers in a modern microkernel-based OS	...
27	http://www.eas.asu.edu/~cse434/	Physical layer basics; network protocol algorithms; error handling; flow control; multihop routing; network reliability, timing, security; data compression; cryptography fundamentals	...
28	http://www.eas.asu.edu/~cse438/	Design and implementtion of systems programs, including text editors, file utilities, monitors, assemblers, relocating linking loaders, I/O handlers, schedulers, etc	...
29	http://www.eas.asu.edu/~cse440/	Introduction to programming language implementation. Implementation strategies such as compilation, interpretation, and translation. Major compilation phases such as lexical analysis, semantic analysis, optimization, and code generation	...
30	http://www.eas.asu.edu/~cse445/	Frameworks for distributed software components. Foundations of client-server computing and architectures for distributed object systems. Dynamic discovery and invocation	...
31	null_no_value	Client-server model for creating window interfaces. Toolkits and libraries such as X11, Microsoft Foundation Classes and Java Abstract Window Toolkit	...
32	null_no_value	Design and analysis of computer algorithms using analytical and empirical methods; complexity measures, design methodologies, and survey of important algorithms	...
33	null_no_value	Theory of grammar, methods of syntactic analysis and specification, types of artificial languages, relationship between formal languages, and automata	...
34	null_no_value	Propositional logic, syntax and semantics, proof theory vs. model theory, soundness, consistency and completeness, first order logic, logical theories, automated theorem proving, ground resolution, pattern matching unification and resolution, Dijkstras logic, proof obligations, and program proving	...
35	null_no_value	Software engineering foundations, formal representations in the software process; use of formalisms in creating a measured and structured working environment	...
36	http://www.eas.asu.edu/~cse461/	First of 2-course software design sequence. Development planning, management; process modeling; incremental and team development using CASE tools	...
37	http://www.eas.asu.edu/~cse462/	Second of 2-course software design sequence. Process, product assessment and improvement; incremental and team development using CASE tools	...

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	MoreInfoURL	DescriptionText	...
38	http://www.eas.asu.edu/~cse470/	Display devices, data structures, transformation, interactive graphics, 3-dimensional graphics, and hidden line problem	...
39	null_no_value	State space search, heuristic search, games, knowledge representation techniques, expert systems, and automated reasoning	...
40	null_no_value	Functional and logic programming using languages like Lucid and Prolog. Typical applications would be a Screen Editor and an Expert System	...
41	http://www.eas.asu.edu/~cse476/	Principles of computational linguistics, formal syntax, and semantics, as applied to the design of software with natural (human) language I/O	...
42	null_no_value	Introduction to parametric curves and surfaces. Bezier and B-spline interpolation, and approximation techniques	...
43	http://www.eas.asu.edu/~cse494db	Advanced data modeling, object-oriented databases, and object-relational databases. Web access to databases. Professionalism and ethics in information access	...
44	http://www.public.asu.edu/~cbaral/cse494-f00/	null_no_value	...
45	http://rakaposhi.eas.asu.edu/cse494/	null_no_value	...
46	http://ceaspub.eas.asu.edu/cse494b/	Train computer science students to be effective information specialists with an entrepreneurial perspective and managerial outlook	...
47	http://shamir.eas.asu.edu/~mcn/cse494sp05.html	Applications (pervasive computing, health-monitoring, home land security), data dissemination and aggregation, security, localization, time synchronization, energy-efficiency, reliability, programming platforms	...
48	http://rts-lab.eas.asu.edu/courses/cse494/	null_no_value	...
49	http://www.eas.asu.edu/~cse507/	Computer generated 3-D environments, spatial presence of virtual objects, technologies of immersion, tracking systems, simulation of reality	...
50	http://www.eas.asu.edu/~cse508/	Digital image fundamentals, image transforms, image enhancement and restoration techniques, image encoding, and segmentation methods	...
51	null_no_value	Implementation of database systems. Data storage, indexing, querying, and retrieval. Query optimization and execution, concurrency control, and transaction management	...
52	http://www.eas.asu.edu/~cse512/	Distributed database design, query processing, and transaction processing. Distributed database architectures and interoperability. Emerging technology	...
53	http://www.eas.asu.edu/~cse513/	Declarative and active rules. Logic as a data model. Evaluation and query optimization. Triggers and ECA rules. Current research topics	...
54	http://www.eas.asu.edu/~cse514/	Object-oriented data modeling, database and language integration, object algebras, extensibility, transactions, object managers, versioning/configuration, active data, nonstandard applications. Research seminar	...
55	null_no_value	Data models for multimedia and Web data; query processing and optimization for inexact retrieval; advanced indexing, clustering, and search techniques	...

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	MoreInfoURL	DescriptionText	...
56	http://www.eas.asu.edu/~cse517/	Introduction to hardware design languages using VHDL. Modeling concepts for specification, simulation, synthesis	...
57	http://www.eas.asu.edu/~cse518/	Modeling VLSI design in hardware design languages for synthesis. Transformation of language-based designs to physical layout. Application of synthesis tools	...
58	null_no_value	Computer architecture description languages, computer arithmetic, memory-hierarchy design, parallel, vector, and multiprocessors, and input/output	...
59	http://www.eas.asu.edu/~cse521/	Microprocessor technology and its application to the design of practical digital systems. Hardware, assembly language programming, and interfacing of microprocessor-based systems	...
60	null_no_value	Developing system software for a multiprocessor, multiprogramming, microprocessor-based system using information and techniques presented in CSE 421, 422	...
61	http://www.eas.asu.edu/~cse526/	Real and apparent concurrency. Hardware organization of multiprocessors, multiple computer systems, scientific attached processors, and other parallel systems	...
62	http://www.eas.asu.edu/~cse530/	Study of the design and implementation of a timeshared multiprogramming operating system, with emphasis on the UNIX operating system	...
63	http://cactus.eas.asu.edu/partha/Teaching/531.2002/	Distributed systems architecture, remote file access, message-based systems, object-based systems, client/server paradigms, distributed algorithms, replication and consistency, and multiprocessor operating systems	...
64	http://www.eas.asu.edu/~cse532/	Memory, processor, process and communication management, and concurrency control in the Windows NT multiprocessor and distributed operating system kernel and servers	...
65	http://www.eas.asu.edu/~cse534/	Advanced network protocols and infrastructure, applications of high-performance networks to distributed systems, high-performance computing and multimedia domains, special features of networks: real-time, security, reliability	...
66	http://www.eas.asu.edu/~cse536s2/	Protection and file systems. Communication, processes, synchronization, naming, fault tolerance, security, data replication, and coherence in distributed systems. Real-time systems	...
67	null_no_value	Principles of ATM networks, switch architecture, traffic management, call and connection control, routing, internetworking with ATM networks, signaling, and OAM	...
68	null_no_value	Use of cryptography for secure protocols over networked systems, including signatures, certificates, timestamps, electrons, digital cash, and other multiparty coordination	...
69	null_no_value	Formal parsing strategies, optimization techniques, code generation, extensibility and transportability considerations, and recent developments	...
70	null_no_value	Language constructs, extensibility and abstractions, and runtime support. Language design process	...
71	null_no_value	Combinatorial algorithms, nondeterministic algorithms, classes P and NP, NP-hard and NP-complete problems, and intractability. Design techniques for fast combinatorial algorithms	...

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	MoreInfoURL	DescriptionText	...
72	null_no_value	Rigorous treatment of regular languages, context-free languages, Turing machines and decidability, reducibility, and other advanced topics in computability theory	...
73	null_no_value	Knowledge acquisition and representation, rule-based systems, frame-based system, validation of knowledge bases, inexact reasoning, and expert database systems	...
74	null_no_value	Software engineering characteristics particular to parallel and distributed systems. Tools and techniques to support software engineering involving parallel processing and distributed systems	...
75	null_no_value	Examination of the definitional stage of software development; analysis of specification representations and techniques emphasizing important application issues	...
76	http://www.eas.asu.edu/~cse564/	Examination of software design issues and techniques. Includes a survey of design representations and a comparison of design methods	...
77	null_no_value	Test planning; requirements-based and code-based testing techniques; tools; reliability models; statistical testing	...
78	null_no_value	Project Management, risk management, configuration management, quality management, simulated project management experience	...
79	null_no_value	Hidden surface algorithms, lighting models, and shading techniques. User interface design. Animation techniques. Fractals and stochastic models. Raster algorithms	...
80	http://www.public.asu.edu/~cbaral/cse571-f99/	Definitions of intelligence, computer problem solving, game playing, pattern recognition, theorem proving, and semantic information processing; evolutionary systems; heuristic programming	...
81	null_no_value	Modeling of natural phenomena: terrain, clouds, fire, water, and trees. Particle systems, deformation of solids, antialiasing, adn volume visualization	...
82	http://rakaposhi.eas.asu.edu/cse574	Reasoning about time and action, plan synthesis and execution, improving planning performance, applications to manufacturing intelligent agents	...
83	null_no_value	Automatic knowledge acquisition, automatic analysis/synthesis of strategies, distributed planning/ problem solving, casual modeling, predictive human-machine environments	...
84	null_no_value	Comparative parsing strategies, scooping and reference problems, nonfirst-order logical semantic representations, and discourse structure	...
85	http://eros.cagd.eas.asu.edu/~farin/classes/cse577/cse577.html	General interpolation; review of curve interpolation and approximation; spline curves; visual smoothness of curves; parameterization of curves; introduction to surface interpolation and approximation	...
86	http://eros.cagd.eas.asu.edu/~farin/classes/cse578/cse578.html	Coons patches and Bezier patches; triangular patches; arbitrarily located data methods; geometry processing of surfaces; higher dimensional surfaces	...
87	http://eros.cagd.eas.asu.edu/~farin/classes/cse579/cse579.html	Projective geometry, NURBs-based modeling, basic theory of conics and rational surfaces, stereographic maps, quadrics, IGES data specification	...

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	MoreInfoURL	DescriptionText	...
88	http://www.eas.asu.edu/~cse591os	null_no_value	...
89	http://www.public.asu.edu/~cbaral/cse591-f01/	null_no_value	...
90	http://www.eas.asu.edu/~csedept/courses/591_computational.htm	null_no_value	...
91	http://www.public.asu.edu/~cbaral/cse591-s03/	null_no_value	...
92	http://www.public.asu.edu/~huanliu/cse591.html	null_no_value	...
93	http://cse.asu.edu/~cse591b/	null_no_value	...
94	http://www.eas.asu.edu/~cse591f/	null_no_value	...
95	http://www.public.asu.edu/~syrotiuk/cse591/index.html	null_no_value	...
96	http://shamir.eas.asu.edu/~cse591tv	null_no_value	...
97	http://www.eas.asu.edu/~hsarjou/Courses/CSE591fall02.pdf	null_no_value	...
98	null_no_value	null_no_value	...
99	null_no_value	null_no_value	...
100	http://www.public.asu.edu/~hdavulcu/CSE591_Semantic_Web_Mining.html	null_no_value	...

Table 21 – Continued

	Responsibility	LectureOrLab	Prerequisites	...
0	Social and ethical responsibility	Lecture, lab	Prerequisite: MAT 170	...
1	Social and ethical responsibility	Lecture, lab	Prerequisite: MAT 170	...
2	null_no_value	Lecture, lab	Prerequisite: Computer Literacy	...
3	null_no_value	null_no_value	null_no_value	...
4	null_no_value	Lecture, lab	Prerequisite: MAT 117	...
5	null_no_value	null_no_value	null_no_value	...
6	null_no_value	null_no_value	null_no_value	...
7	null_no_value	null_no_value	Prerequisites: One year of high-school programming with Pascal, C++ or Java; or CSE 100 or CSE 110	...
8	null_no_value	null_no_value	Prerequisite : CSE 200	...
9	null_no_value	Lecture, lab	Prerequisites: CSE 100 (or 110 or 200), 120 (or EEE 120)	...

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	Responsibility	LectureOrLab	Prerequisites	...
10	null_no_value	Lecture, lab	Prerequisites: CSE 100 (or 110 or 200), 120 (or EEE 120)	...
11	null_no_value	Lecture, lab	Prerequisite: CSE 210	...
12	null_no_value	null_no_value	null_no_value	...
13	null_no_value	null_no_value	Prerequiste: CSE 210, MAT 243	...
14	null_no_value	null_no_value	Prerequisite: CSE/EEE 225 or CSE/EEE 226	...
15	null_no_value	null_no_value	Prerequisites: CSE 240, CSE 310, CSE/EEE 225 or 226	...
16	null_no_value	null_no_value	Prerequisite: CSE 310	...
17	null_no_value	null_no_value	Prerequisite: CSE 240 and CSE 210	...
18	null_no_value	null_no_value	Prerequisite: CSE 310	...
19	null_no_value	null_no_value	Prerequisite: CSE 310	...
20	null_no_value	null_no_value	Prerequisite: CSE 330	...
21	null_no_value	Lecture, lab	Prerequisite: CSE/EEE 225	...
22	null_no_value	null_no_value	Prerequisite: CSE 421	...
23	null_no_value	null_no_value	Prerequisite: CSE 422	...
24	null_no_value	null_no_value	Prerequisite: CSE 330	...
25	null_no_value	null_no_value	Prerequisites: CSE 330, 340	...
26	null_no_value	null_no_value	Prerequisite: CSE 430	...
27	null_no_value	null_no_value	Prerequisite: CSE 330	...
28	null_no_value	null_no_value	Prerequisite: CSE 421 or instructor approval	...
29	null_no_value	null_no_value	Prerequisites: CSE 340, 355	...
30	null_no_value	null_no_value	Prerequisites: CSE 360	...
31	null_no_value	null_no_value	Prerequisites: CSE 310	...
32	null_no_value	null_no_value	Prerequisite: CSE 310	...
33	null_no_value	null_no_value	Prerequisite: CSE 355	...
34	null_no_value	null_no_value	Prerequisite: CSE 355	...
35	null_no_value	null_no_value	Prerequisite: CSE 360	...
36	null_no_value	null_no_value	Prerequisite: CSE 360	...
37	null_no_value	null_no_value	Prerequisite: CSE 461	...
38	null_no_value	null_no_value	Prerequisites: CSE 310; MAT 342	...
39	null_no_value	null_no_value	Prerequisite: CSE 240, 310	...
40	null_no_value	null_no_value	Prerequisite: CSE 355	...
41	null_no_value	null_no_value	Prerequisite: CSE 310 or instructor approval	...
42	null_no_value	null_no_value	Prerequisites: CSE 210, CSE 470; MAT 342	...
43	null_no_value	null_no_value	Prerequisite: CSE 412	...
44	null_no_value	null_no_value	null_no_value	...
45	null_no_value	null_no_value	null_no_value	...
46	null_no_value	null_no_value	null_no_value	...
47	null_no_value	null_no_value	null_no_value	...
48	null_no_value	null_no_value	null_no_value	...
49	null_no_value	null_no_value	Prerequisites: CSE 408 or CSE 508 or CSE 470 or instructor approval	...
50	null_no_value	null_no_value	Prerequisite: EEE 303 or instructor approval	...
51	null_no_value	null_no_value	Prerequisite: CSE 412	...
52	null_no_value	null_no_value	Prerequisite: CSE 412	...
53	null_no_value	null_no_value	Prerequisite: CSE 412	...
54	null_no_value	null_no_value	Prerequisite: CSE 510	...
55	null_no_value	null_no_value	Prerequisites: CSE 408, 412	...
56	null_no_value	null_no_value	null_no_value	...

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	Responsibility	LectureOrLab	Prerequisites	...
57	null_no_value	null_no_value	Prerequisite: CSE 517	...
58	null_no_value	null_no_value	null_no_value	...
59	null_no_value	Lecture, lab	Prerequisite: CSE 421	...
60	null_no_value	null_no_value	Prerequisite: CSE 422	...
61	null_no_value	null_no_value	Prerequisite: CSE 330 or 423	...
62	null_no_value	null_no_value	Prerequisites: CSE 430; knowledge of C Language	...
63	null_no_value	null_no_value	Prerequisite: CSE 432 or instructor approval	...
64	null_no_value	null_no_value	Prerequisite: CSE 530 and either CSE 531 or CSE 536	...
65	null_no_value	null_no_value	Prerequisite: CSE 434	...
66	null_no_value	null_no_value	Prerequisite: CSE 430	...
67	null_no_value	null_no_value	Prerequisite: CSE 434	...
68	null_no_value	null_no_value	Prerequisite: CSE 310 or instructor approval	...
69	null_no_value	null_no_value	Prerequisite: CSE 440	...
70	null_no_value	null_no_value	Prerequisite: CSE 440	...
71	null_no_value	null_no_value	Prerequisite: CSE 450	...
72	null_no_value	null_no_value	Prerequisite: CSE 355	...
73	null_no_value	null_no_value	Prerequisite CSE 471	...
74	null_no_value	null_no_value	Prerequisite: CSE 360	...
75	null_no_value	null_no_value	Prerequisite: CSE 460	...
76	null_no_value	null_no_value	Prerequisite: CSE 460	...
77	null_no_value	null_no_value	Prerequisite: CSE 460	...
78	null_no_value	null_no_value	Prerequisite: CSE 460	...
79	null_no_value	null_no_value	Prerequisite: CSE 470	...
80	null_no_value	null_no_value	Prerequisite: CSE 471	...
81	null_no_value	Lecture, Lab	Prerequisite: CSE 470	...
82	null_no_value	null_no_value	Prerequisite: CSE 471	...
83	null_no_value	null_no_value	Prerequisite: CSE 571	...
84	null_no_value	null_no_value	Prerequisite: CSE 476	...
85	null_no_value	null_no_value	Prerequisites: CSE 470 and 477	...
86	null_no_value	null_no_value	Prerequisites: CSE 470 and 477	...
87	null_no_value	null_no_value	Prerequisites: CSE 470 and 477	...
88	null_no_value	null_no_value	null_no_value	...
89	null_no_value	null_no_value	null_no_value	...
90	null_no_value	null_no_value	null_no_value	...
91	null_no_value	null_no_value	null_no_value	...
92	null_no_value	null_no_value	null_no_value	...
93	null_no_value	null_no_value	null_no_value	...
94	null_no_value	null_no_value	null_no_value	...
95	null_no_value	null_no_value	null_no_value	...
96	null_no_value	null_no_value	null_no_value	...
97	null_no_value	null_no_value	null_no_value	...
98	null_no_value	null_no_value	null_no_value	...
99	null_no_value	null_no_value	null_no_value	...
100	null_no_value	null_no_value	null_no_value	...

Table 21 – Continued

	CrossListed	StudiesType	Restrictions
0	null_no_value	General Studies: CS	null_no_value
1	null_no_value	null_no_value	null_no_value
2	Cross-listed with EEE 120	null_no_value	null_no_value
3	null_no_value	General Studies : CS	May be taken for credit on either IBM PC or Macintosh, but not both. Non-majors only
4	null_no_value	General Studies: CS	Non-majors only
5	null_no_value	null_no_value	null_no_value
6	null_no_value	null_no_value	null_no_value
7	null_no_value	General Studies: CS	null_no_value
8	null_no_value	General Studies : CS	null_no_value
9	Cross-listed as EEE 225	null_no_value	Credit is allowed for only CSE 225 or EEE 225
10	Cross-listed as EEE 226	null_no_value	Credit is allowed for only CSE 226 or EEE 226
11	null_no_value	null_no_value	null_no_value
12	null_no_value	null_no_value	null_no_value
13	null_no_value	null_no_value	null_no_value
14	null_no_value	null_no_value	null_no_value
15	null_no_value	null_no_value	null_no_value
16	null_no_value	null_no_value	null_no_value
17	null_no_value	null_no_value	null_no_value
18	null_no_value	null_no_value	null_no_value
19	null_no_value	null_no_value	null_no_value
20	null_no_value	null_no_value	null_no_value
21	null_no_value	null_no_value	null_no_value
22	null_no_value	null_no_value	Requires assembly language programming
23	null_no_value	General Studies	null_no_value
24	null_no_value	null_no_value	null_no_value
25	null_no_value	null_no_value	null_no_value
26	null_no_value	null_no_value	null_no_value
27	null_no_value	null_no_value	null_no_value
28	null_no_value	General Studies: L	null_no_value
29	null_no_value	null_no_value	null_no_value
30	null_no_value	null_no_value	null_no_value
31	null_no_value	null_no_value	null_no_value
32	null_no_value	null_no_value	null_no_value
33	Cross-listed as MAT 401	null_no_value	null_no_value
34	null_no_value	null_no_value	null_no_value
35	null_no_value	null_no_value	null_no_value
36	null_no_value	null_no_value	null_no_value
37	null_no_value	null_no_value	null_no_value
38	null_no_value	null_no_value	null_no_value
39	null_no_value	null_no_value	null_no_value
40	null_no_value	null_no_value	null_no_value
41	null_no_value	null_no_value	null_no_value
42	null_no_value	null_no_value	null_no_value
43	null_no_value	null_no_value	null_no_value
44	null_no_value	null_no_value	null_no_value

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	CrossListed	StudiesType	Restrictions
45	null_no_value	null_no_value	null_no_value
46	null_no_value	null_no_value	null_no_value
47	null_no_value	null_no_value	null_no_value
48	null_no_value	null_no_value	null_no_value
49	null_no_value	null_no_value	null_no_value
50	null_no_value	null_no_value	null_no_value
51	null_no_value	null_no_value	null_no_value
52	null_no_value	null_no_value	null_no_value
53	null_no_value	null_no_value	null_no_value
54	null_no_value	null_no_value	null_no_value
55	null_no_value	null_no_value	null_no_value
56	null_no_value	null_no_value	null_no_value
57	null_no_value	null_no_value	null_no_value
58	null_no_value	null_no_value	null_no_value
59	null_no_value	null_no_value	null_no_value
60	null_no_value	null_no_value	null_no_value
61	null_no_value	null_no_value	null_no_value
62	null_no_value	null_no_value	null_no_value
63	null_no_value	null_no_value	null_no_value
64	null_no_value	null_no_value	null_no_value
65	null_no_value	null_no_value	null_no_value
66	null_no_value	null_no_value	null_no_value
67	null_no_value	null_no_value	null_no_value
68	null_no_value	null_no_value	null_no_value
69	null_no_value	null_no_value	null_no_value
70	null_no_value	null_no_value	null_no_value
71	null_no_value	null_no_value	null_no_value
72	null_no_value	null_no_value	null_no_value
73	null_no_value	null_no_value	null_no_value
74	null_no_value	null_no_value	null_no_value
75	null_no_value	null_no_value	null_no_value
76	null_no_value	null_no_value	null_no_value
77	null_no_value	null_no_value	null_no_value
78	null_no_value	null_no_value	null_no_value
79	null_no_value	null_no_value	null_no_value
80	null_no_value	null_no_value	null_no_value
81	null_no_value	null_no_value	null_no_value
82	null_no_value	null_no_value	null_no_value
83	null_no_value	null_no_value	null_no_value
84	null_no_value	null_no_value	null_no_value
85	null_no_value	null_no_value	null_no_value
86	null_no_value	null_no_value	null_no_value
87	null_no_value	null_no_value	null_no_value
88	null_no_value	null_no_value	null_no_value
89	null_no_value	null_no_value	null_no_value
90	null_no_value	null_no_value	null_no_value
91	null_no_value	null_no_value	null_no_value
92	null_no_value	null_no_value	null_no_value
93	null_no_value	null_no_value	null_no_value
94	null_no_value	null_no_value	null_no_value

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	CrossListed	StudiesType	Restrictions
95	null_no_value	null_no_value	null_no_value
96	null_no_value	null_no_value	null_no_value
97	null_no_value	null_no_value	null_no_value
98	null_no_value	null_no_value	null_no_value
99	null_no_value	null_no_value	null_no_value
100	null_no_value	null_no_value	null_no_value

Conflict Resolution: As a first approach, entry-level courses can be regarded as courses which either explicitly state to have no prerequisites or for which no prerequisites can be found in data. Hence, a corresponding SIQL query can be formulated as follows:

Listing 11: SIQL Solution 1 for THALIA Benchmark Query 7

```
0  select * from (
1          (select * from UniMichiganCSCourse)
2          outer union
3          (select CourseNumber as CatalogNumber, Title as Name,
4          CreditHours as Credits, MoreInfoURL, DescriptionText as Description,
5          Responsibility, LectureOrLab, Prerequisites as Prerequisite,
6          CrossListed, StudiesType, Restrictions from ArizonaStateCSCourse))
7  where Prerequisite = "none" or Prerequisite is null;
```

Alternatively, an attribute transformation function can be implemented that does the inferencing of course prerequisites as requested by the current THALIA benchmark query. Thus, whenever there is no explicit information about prerequisites in the value of the Prerequisite attribute, then the function returns "none". In our case, class ch.uzh.ifi.sirup.siql.functions.attribute.PrerequisiteInference provides such an inference service; it is registered to SIRUP as follows:

Listing 12: Registering the Attribute Transformation Function prereq with SIQL

```
0  create function prereq
1  using class ch.uzh.ifi.sirup.siql.functions.attribute.PrerequisiteInference;
```

Given this new function prereq, the SIQL solution query from Listing 11 can be reformulated as shown in Listing 13:

Listing 13: SIQL Solution 2 for THALIA Benchmark Query 7

```
0  select * from (
1          (select Subject, CatalogNumber, Name, prereq(Prerequisite) as
2          Prerequisite, Field, Credits, Description from UniMichiganCSCourse)
3          outer union
4          (select CourseNumber as CatalogNumber, Title as Name,
5          CreditHours as Credits, MoreInfoURL, DescriptionText as Description,
6          Responsibility, LectureOrLab, prereq(Prerequisites) as Prerequisite,
7          CrossListed, StudiesType, Restrictions from ArizonaStateCSCourse) )
8  where Prerequisite = "none";
```

Result: Based on the query from Listing 13, the requested information on all entry-level courses is shown in the following table (note the prerequisites in the "Prerequisite" attribute):

Table 22: Result Data for SIQL Query from Listing 13

	Subject	CatalogNumber	Name	...
0	EECS	181	Introduction to Computer Systems	...
1	EECS	990	Dissertation/Pre-Candidate	...
2	null_no_attribute	180	Computer Literacy	...
3	null_no_attribute	185	Internet and the World Wide Web	...
4	null_no_attribute	194	Introduction to Engineering Design	...
5	null_no_attribute	300	Intermediate Engineering Design	...
6	null_no_attribute	494	Building and programming mobile robots	...
7	null_no_attribute	494	Information Retrieval, Mining and Integration on the Internet	...
8	null_no_attribute	494	Principles of Information Engineering	...
9	null_no_attribute	494	Real-Time Embedded Systems	...
10	null_no_attribute	494/598	Wireless Sensor Networks	...
11	null_no_attribute	517	Hardware Design Languages	...
12	null_no_attribute	520	Computer Architecture II	...
13	null_no_attribute	591	Advanced Topics on Parallel and Distributed Computing	...
14	null_no_attribute	591	Autonomous Agents: theory and practice	...
15	null_no_attribute	591	Computational Algorithms for Systems Biology	...
16	null_no_attribute	591	Computational Molecular Biology	...
17	null_no_attribute	591	Data Mining	...
18	null_no_attribute	591	Hardware-Software Co-design	...
19	null_no_attribute	591	Image Processing-II Digital Video processing	...
20	null_no_attribute	591	Mobile Ad Hoc Networking Computing	...
21	null_no_attribute	591	Mobile Computing	...
22	null_no_attribute	591	Object Oriented Modeling Simulation	...
23	null_no_attribute	591	Practical Operating System Internals	...
24	null_no_attribute	591	Randomized and Approximation Algorithms	...
25	null_no_attribute	591	Semantic Web Mining	...

Table 22 – Continued

	Prerequisite	Field	Credits	Description	...
0	none	I	4	Fundamental computer skills needed to increase productivity. Use of software packages and applications including word processors, web browsers, spreadsheets, database systems. Creating a web home page. History of computing, ethics and legal issues. Introduction to basic hardware components. Intended for non CE/CS/EE majors whose goal is computer literacy.	...

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	Prerequisite	Field	Credits	Description	...
1	none	I	2 8	Dissertation work by doctoral student not yet admitted to status as candidate. The defense of the dissertation, that is, the fi nal oral examination, must be held under a full-term candidacy enrollment.	...
2	none	null_no_attribute	3	Introduction to general problem-solving approaches using widely available software tools such as database packages, word processors, spreadsheets, and report generators	...
3	none	null_no_attribute	3	Fundamental Internet concepts. World Wide Web browsing, searching, publishing, advanced Internet productivity tools	...
4	none	null_no_attribute	null_no_value	null_no_value	...
5	none	null_no_attribute	3	null_no_value	...
6	none	null_no_attribute	3	null_no_value	...
7	none	null_no_attribute	3	null_no_value	...
8	none	null_no_attribute	3	Train computer science students to be effective information specialists with an entrepreneurial perspective and managerial outlook	...
9	none	null_no_attribute	3	null_no_value	...
10	none	null_no_attribute	3	Applications (pervasive computing, health-monitoring, home land security), data dissemination and aggregation, security, localization, time synchronization, energy-efficiency, reliability, programming platforms	...
11	none	null_no_attribute	3	Introduction to hardware design languages using VHDL. Modeling concepts for specification, simulation, synthesis	...
12	none	null_no_attribute	3	Computer architecture description languages, computer arithmetic, memory-hierarchy design, parallel, vector, and multiprocessors, and input/output	...
13	none	null_no_attribute	3	null_no_value	...
14	none	null_no_attribute	3	null_no_value	...
15	none	null_no_attribute	3	null_no_value	...
16	none	null_no_attribute	3	null_no_value	...
17	none	null_no_attribute	3	null_no_value	...
18	none	null_no_attribute	3	null_no_value	...
19	none	null_no_attribute	3	null_no_value	...
20	none	null_no_attribute	3	null_no_value	...
21	none	null_no_attribute	3	null_no_value	...
22	none	null_no_attribute	3	null_no_value	...
23	none	null_no_attribute	3	null_no_value	...
24	none	null_no_attribute	3	null_no_value	...

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	Prerequisite	Field	Credits	Description	...
25	none	null_no_attribute	3	null_no_value	...

Table 22 – Continued

	MoreInfoURL	Responsibility	LectureOrLab	CrossListed	...
0	null_no_attribute	null_no_attribute	null_no_attribute	null_no_attribute	...
1	null_no_attribute	null_no_attribute	null_no_attribute	null_no_attribute	...
2	http://www.eas.asu.edu/∼cse180	null_no_value	null_no_value	null_no_value	...
3	http://www.eas.asu.edu/∼cse185	null_no_value	null_no_value	null_no_value	...
4	http://www.eas.asu.edu/ ∼hasancam/courses/Spring-2002/ ece194/ece194.html	null_no_value	null_no_value	null_no_value	...
5	http://www.eas.asu.edu/ ∼ece300/	null_no_value	null_no_value	null_no_value	...
6	http://www.public.asu.edu/ ∼cbaral/cse494-f00/	null_no_value	null_no_value	null_no_value	...
7	http://rakaposhi.eas.asu.edu/ cse494/	null_no_value	null_no_value	null_no_value	...
8	http://ceaspub.eas.asu.edu/ cse494b/	null_no_value	null_no_value	null_no_value	...
9	http://rts-lab.eas.asu.edu/courses/cse494/	null_no_value	null_no_value	null_no_value	...
10	http://shamir.eas.asu.edu/ ∼mcn/cse494sp05.html	null_no_value	null_no_value	null_no_value	...
11	http://www.eas.asu.edu/ ∼cse517/	null_no_value	null_no_value	null_no_value	...
12	null_no_value	null_no_value	null_no_value	null_no_value	...
13	http://www.eas.asu.edu/ ∼cse591os	null_no_value	null_no_value	null_no_value	...
14	http://www.public.asu.edu/ ∼cbaral/cse591-f01/	null_no_value	null_no_value	null_no_value	...
15	http://www.eas.asu.edu/ ∼csedept/courses/ 591_computational.htm	null_no_value	null_no_value	null_no_value	...
16	http://www.public.asu.edu/ ∼cbaral/cse591-s03/	null_no_value	null_no_value	null_no_value	...
17	http://www.public.asu.edu/ ∼huanliu/cse591.html	null_no_value	null_no_value	null_no_value	...
18	http://cse.asu.edu/ ∼cse591b/	null_no_value	null_no_value	null_no_value	...
19	http://www.eas.asu.edu/ ∼cse591f/	null_no_value	null_no_value	null_no_value	...
20	http://www.public.asu.edu/ ∼syrotiuk/cse591/index.html	null_no_value	null_no_value	null_no_value	...
21	http://shamir.eas.asu.edu/ ∼cse591tv	null_no_value	null_no_value	null_no_value	...
22	http://www.eas.asu.edu/∼hsar-jou/Courses/CSE591fall02.pdf	null_no_value	null_no_value	null_no_value	...

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	MoreInfoURL	Responsibility	LectureOrLab	CrossListed	...
23	null_no_value	null_no_value	null_no_value	null_no_value	...
24	null_no_value	null_no_value	null_no_value	null_no_value	...
25	http://www.public.asu.edu/~hdavulcu/CSE591_Semantic_Web_Mining.html	null_no_value	null_no_value	null_no_value	...

Table 22 – Continued

	StudiesType	Restrictions
0	null_no_attribute	null_no_attribute
1	null_no_attribute	null_no_attribute
2	General Studies : CS	May be taken for credit on either IBM PC or Macintosh, but not both. Non-majors only
3	null_no_value	null_no_value
4	null_no_value	null_no_value
5	null_no_value	null_no_value
6	null_no_value	null_no_value
7	null_no_value	null_no_value
8	null_no_value	null_no_value
9	null_no_value	null_no_value
10	null_no_value	null_no_value
11	null_no_value	null_no_value
12	null_no_value	null_no_value
13	null_no_value	null_no_value
14	null_no_value	null_no_value
15	null_no_value	null_no_value
16	null_no_value	null_no_value
17	null_no_value	null_no_value
18	null_no_value	null_no_value
19	null_no_value	null_no_value
20	null_no_value	null_no_value
21	null_no_value	null_no_value
22	null_no_value	null_no_value
23	null_no_value	null_no_value
24	null_no_value	null_no_value
25	null_no_value	null_no_value

9 Benchmark Query 8: Semantic Incompatibility

Conflict: In the eighth THALIA query, all database courses open to junior-level students are requested. The given course data for this query is from the Georgia Institute of Technology and the Swiss Federal Institute of Technology Zürich (ETH). The challenge for the data integration system here is to deal with the problem that the concept of student classification according to “freshman”, “sophomore”, etc. used in American Universities does not exist in Swiss Universities.

Source Data: See Table 2 (IConcept GeorgiaTechCSCourse) and Table 13 (IConcept ETHZCS-Course. Note that the given sample value used in the description for benchmark query 8 in [HST04] with "JR or SR" as its restrictions does not exist in the benchmark data for the Georgia Institute of Technology; in the given data, the prerequisites attribute value is null_no_value (see Record 7 in Table 2).

Conflict Resolution: Following [HST04], more than one kind of null value must be supported to handle this benchmark query intelligently. Specifically, "data missing but could be present" has to be distinguished from "data missing and cannot be present". As already shown in benchmark query 6, SIRUP supports two different null values are for this: null_no_value and null_no_attribute. Based on this, we are ready to prove in THALIA benchmark query 8 that the integration system under examination is capable of supporting different types of null values. Therefore, we use the following SIQL query to coalesce the given two sets of courses:

Listing 14: SIQL Solution 1 for THALIA Benchmark Query 8

```
0  select ∗ from (
1          (select ∗ from GeorgiaTechCSCourse)
2          outer union
3          (select c.Nummer as CRN, Titel as Title, Nachname as Instructor,
4          Semester, Homepage, Sprache, Umfang, UnterrichtTyp from
5                  (select ∗ from ETHZCSCourse) as c
6                  inner join
7                  (select ∗ from ETHZCSLecturer) as l
8                  on c.Nummer = l.Nummer) )
9  where matches(Restrictions, "(.)∗JR(.)∗") = true;
```

This query yields the following result:

Table 23: Result Data for SIQL Query from Listing 14

	Department	Code	Section	Mode	CRN	Title	Hours	In	...
0	CS	4001	A	L	25727	Computing Society	3	40	...
1	CS	4001	B	L	25728	Computing Society	3	41	...
2	CS	4001	D	L	25740	Computing Society	3	37	...

Table 23 – Continued

	Max	Days	TimeBegin	TimeEnd	Instructor	Room	Building	...
0	42	TR	0305pm	0425pm	Rugaber	320	Cherry Emerson	...
1	42	MWF	0105pm	0155pm	Shaw	101	Coll of Computing	...
2	42	TR	0435pm	0555pm	Harrold	S204	Howey (Physics)	...

Table 23 – Continued

	Description	Restrictions	Prerequisites	...
0	null_no_value	Course restricted: Only class JR SR.	null_no_value	...
1	null_no_value	Course restricted: Only class JR SR.	null_no_value	...
2	null_no_value	Course restricted: Only class JR SR.	null_no_value	...

Table 23 – Continued

	Semester	Homepage	Sprache	Umfang	UnterrichtTyp
0	null_no_attribute	null_no_attribute	null_no_attribute	null_no_attribute	null_no_attribute
1	null_no_attribute	null_no_attribute	null_no_attribute	null_no_attribute	null_no_attribute
2	null_no_attribute	null_no_attribute	null_no_attribute	null_no_attribute	null_no_attribute

However, a more sophisticated approach can be taken for benchmark query 8. That is, the challenge of THALIA benchmark query 8 can also be resolved differently if we assume that the "Semester" attribute of the ETH Zurich course data is interpreted in the sense of the "Restrictions" attribute of the Georgia Institute of Technology. In the United States, a junior is a student in the third year of his academic education [Sin00]. Hence, the given example course restriction "open to juniors" can be converted by an attribute transformation function to express that the particular course can only be taken by students who are in the third year of their curriculum. In this sense, the integration problem of the given example in THALIA benchmark query 8 can be reduced to a "simple mapping" problem that is covered by benchmark query 2 (see Section 3). To realize this conversion, we create a function ger2amStudClass and register it to SIRUP:

Listing 15: Registering the Attribute Transformation Function ger2amStudClass with SIQL

```
0  create function ger2amStudClass using class
1  ch.uzh.ifi.sirup.siql.functions.attribute.German2AmericanStudentClassification;
```

With this new function ger2amStudClass, the SIQL solution query from Listing 14 can be reformulated as follows:

Listing 16: SIQL Solution 2 for THALIA Benchmark Query 8

```
0  select * from (
1          (select * from GeorgiaTechCSCourse)
2          outer union
3          (select c.Nummer as CRN, Titel as Title, Nachname as Instructor,
4          ger2amStudClass(Semester) as Restrictions, Semester, Homepage,
5          Sprache, Umfang, UnterrichtTyp from
6                  (select * from ETHZCSCourse) as c
7                  inner join
8                  (select * from ETHZCSLecturer) as l
9                  on c.Nummer = l.Nummer) )
10 where matches(Restrictions, "(.)*JR(.)*") = true;
```

Result: Based on the query from Listing 16, the requested information on all database courses open to junior-level students is shown in the following table (note the values in "Restrictions" and "Semester"):

Table 24: Result Data for SIQL Query from Listing 16

	Department	Code	Section	Mode	CRN	...
0	CS	4001	A	L	25727	...
1	CS	4001	B	L	25728	...
2	CS	4001	D	L	25740	...
3	null_no_attribute	null_no_attribute	null_no_attribute	null_no_attribute	251-0831-00	...
4	null_no_attribute	null_no_attribute	null_no_attribute	null_no_attribute	251-0831-00	...

Table 24 – Continued

	Title	Hours	In	Max	...
0	Computing Society	3	40	42	...
1	Computing Society	3	41	42	...
2	Computing Society	3	37	42	...
3	Informatik II (D-MAVT)	null_no_attribute	null_no_attribute	null_no_attribute	...
4	Informatik II (D-MAVT)	null_no_attribute	null_no_attribute	null_no_attribute	...

Table 24 – Continued

	Days	TimeBegin	TimeEnd	Instructor	Room	...
0	TR	0305pm	0425pm	Rugaber	320	...
1	MWF	0105pm	0155pm	Shaw	101	...
2	TR	0435pm	0555pm	Harrold	S204	...
3	null_no_attribute	null_no_attribute	null_no_attribute	Koumoutsakos	null_no_attribute	...
4	null_no_attribute	null_no_attribute	null_no_attribute	Schiele	null_no_attribute	...

Table 24 – Continued

	Building	Description	Restrictions	...
0	Cherry Emerson	null_no_value	Course restricted: Only class JR SR.	...
1	Coll of Computing	null_no_value	Course restricted: Only class JR SR.	...
2	Howey (Physics)	null_no_value	Course restricted: Only class JR SR.	...
3	null_no_attribute	null_no_attribute	JR	...
4	null_no_attribute	null_no_attribute	JR	...

Table 24 – Continued

	Prerequisites	Semester	Homepage	Sprache	...
0	null_no_value	null_no_attribute	null_no_attribute	null_no_attribute	...
1	null_no_value	null_no_attribute	null_no_attribute	null_no_attribute	...
2	null_no_value	null_no_attribute	null_no_attribute	null_no_attribute	...
3	null_no_attribute	5. Semester	null_no_value	Deutsch	...
4	null_no_attribute	5. Semester	null_no_value	Deutsch	...

Table 24 – Continued

	Umfang	UnterrichtTyp
0	null_no_attribute	null_no_attribute
1	null_no_attribute	null_no_attribute
2	null_no_attribute	null_no_attribute
3	4G	Informatik für Nichtinformatiker
4	4G	Informatik für Nichtinformatiker

10 Benchmark Query 9: Same Attribute in Different Structure

Conflict: In THALIA query 9, information on the room is requested in which the software engineering course is held. The given course data for this query is from Brown University and University of Maryland. The challenge for the data integration system here is to determine that room information in the University of Maryland's course catalog is available as part of the time information for the different course sections.

Source Data: See Table 11 (IConcept BrownUniCSCourse), Table 8 (IConcept UniMarylandCS-Course), Table 9 (IConcept UniMarylandCSCourseSection), and Table 10 (IConcept UniMaryland-CSCourseSectionEvent).

Conflict Resolution: In this benchmark query, the same two data sources are used as in benchmark query 3 (see Section 4); hence, the same explanations as presented in Section 4 generally apply. That is, normalization of source data relieves the data integration system from having to correctly interpret selected parts of composite values. In analogy to the presented solution of benchmark query 3, the normalized source data is combined and checked with the matches function whether the title of the particular course contains the character sequence "Software Engineering" in order to determine the result as demanded in the current benchmark query. This is shown in the following SIQL query:

Listing 17: SIQL Solution for THALIA benchmark query 9

```
0  select ∗ from (
1          (select ∗ from BrownUniCSCourse)
2          outer union
3          (select c.Code, s.TitleCode, CourseName as Title, Credits,
4          GradeMethod, Instructor, Seats, Open, Waitlist, Days, TimeBegin,
5          TimeEnd, Room from (
6                  (       (select ∗ from UniMarylandCSCourse) as c
7                          inner join
8                          (select ∗ from UniMarylandCSCourseSection) as s
9                          on c.code = s.code)
10                 inner join
11                 (select ∗ from UniMarylandCSCourseSectionEvent) as e
12                 on e.code = c.code and s.titlecode = e.titlecode)))
13 where matches(Title, "(.)∗Software Engineering(.)∗") = true;
```

Result: The requested information on the room in which the software engineering course is held is shown in attribute "Room" in the following table:

Table 25: Result Data for SIQL Query from Listing 17

	Code	InstructorURL	Instructor	CourseURL	...
0	CS032	http://www.cs.brown.edu/~spr/	Reiss	http://www.cs.brown.edu/courses/cs032/	...
1	CMSC435	null_no_attribute	null_no_value	null_no_attribute	...
2	CMSC435	null_no_attribute	Memon	null_no_attribute	...
3	CMSC435	null_no_attribute	null_no_value	null_no_attribute	...
4	CMSC838P	null_no_attribute	null_no_value	null_no_attribute	...

Table 25 – Continued

	Title	HoursType	Days	TimeBegin	...
0	Intro. to Software Engineering	K hr.	T,Th	2:30pm	...
1	Software Engineering	null_no_attribute	TuTh	2:00pm	...
2	Software Engineering	null_no_attribute	TuTh	9:30am	...
3	Software Engineering	null_no_attribute	TuTh	11:00am	...
4	Advanced Topics in Programming Languages: Software Engineering: Remote Analysis and Measurement of Software Systems	null_no_attribute	TuTh	9:30am	...

Table 25 – Continued

	TimeEnd	Room	TitleCode	Credits	...
0	4pm	CIT 165, Labs in Sunlab	null_no_attribute	null_no_attribute	...
1	3:15pm	CSI 1121	0101(13795)	(3 credits)	...
2	10:45am	CSI 2107	0201(13796)	(3 credits)	...
3	12:15pm	CSI 2120	0301(13797)	(3 credits)	...
4	10:45am	CSI 2120	0101(14489)	(3 credits)	...

Table 25 – Continued

	GradeMethod	Seats	Open	Waitlist
0	null_no_attribute	null_no_attribute	null_no_attribute	null_no_attribute
1	REG. CORE Capstone (CS) Course.	null_no_value	null_no_value	null_no_value
2	REG. CORE Capstone (CS) Course.	40	2	0
3	REG. CORE Capstone (CS) Course.	null_no_value	null_no_value	null_no_value
4	REG/AUD.	null_no_value	null_no_value	null_no_value

11 Benchmark Query 10: Handling Sets

Conflict: In the tenth THALIA query, all instructors for courses on software systems are requested. The given course data for this query is from Carnegie Mellon University and University of Maryland. The challenge for the data integration system here is to determine that instructor information is stored as part of the section information in the University of Maryland source data.

Source Data: See Table 3 (IConcept CarnegieMellonCSCourse), Table 4 (IConcept CarnegieMellonCSLecturer), Table 8 (IConcept UniMarylandCSCourse), Table 9 (IConcept UniMarylandCSCourseSection), and Table 10 (IConcept UniMarylandCSCourseSectionEvent). Note that the course entitled "Software Engineering" given by the instructor called "Singh" as shown in [HST04] does not exist in the given course data from Carnegie Mellon University.

Conflict Resolution: Based on the normalizations of composite and set-oriented values, this benchmark query can be handled analogously to previous benchmark queries. That is, joins and an outer union can be employed to create integrated records which are then checked whether their title contains the character sequence "Software" (i.e., to find the courses on software systems). This is shown in the following SIQL query:

Listing 18: SIQL Solution for THALIA Benchmark Query 10

```
0  select ∗ from (
1          (select c.Code, c.Sec, CourseX−Listed, CourseTitle, Room, Day,
2          TimeBegin, TimeEnd, Units, Lecturer from
3                  (select ∗ from CarnegieMellonCSCourse) as c
4                  inner join
5                  (select ∗ from CarnegieMellonCSLecturer) as l
6                  on c.code = l.code and l.sec = c.sec)
7          outer union
8          (select c.Code, s.TitleCode, CourseName as CourseTitle, Credits,
9          GradeMethod, Instructor as Lecturer, Seats, Open, Waitlist,
10         Days as Day, TimeBegin, TimeEnd, Room from (
11                 (          (select ∗ from UniMarylandCSCourse) as c
12                             inner join
13                             (select ∗ from UniMarylandCSCourseSection) as s
14                             on c.code = s.code)
15                 inner join
16                 (select ∗ from UniMarylandCSCourseSectionEvent) as e
17                 on e.code = c.code and s.titlecode = e.titlecode)) )
18 where matches(CourseTitle, "(.)∗Software(.)∗") = true;
```

Result: The requested information on all instructors for courses on software systems is shown in the following table (see attribute "Lecturer" and "Title"):

Table 26: Result Data for SIQL Query from Listing 18

	Code	Sec	CourseX-Listed	CourseTitle	...
0	15-820	B	.	Seminar in Software Systems: Queueing Theory and Scheduling	...
1	15-829	F	18-732	Secure Software Systems	...
2	15-829	F	18-732	Secure Software Systems	...
3	CMSC435	null_no_attribute	null_no_attribute	Software Engineering	...
4	CMSC435	null_no_attribute	null_no_attribute	Software Engineering	...
5	CMSC435	null_no_attribute	null_no_attribute	Software Engineering	...
6	CMSC838P	null_no_attribute	null_no_attribute	Advanced Topics in Programming Languages: Software Engineering: Remote Analysis and Measurement of Software Systems	...
7	CMSC838T	null_no_attribute	null_no_attribute	Advanced Topics in Programming Languages: Systems Software for High Performance Computing, Emphasis on Bioinformatic Applications	...

Table 26 – Continued

	Room	Day	TimeBegin	TimeEnd	Units	...
0	WeH 8220	T	12:00pm	1:50pm	6	...
1	MW W	null_no_value	12pm	null_no_value	null_no_value	...
2	MW W	null_no_value	12pm	null_no_value	null_no_value	...
3	CSI 1121	TuTh	2:00pm	3:15pm	null_no_attribute	...
4	CSI 2107	TuTh	9:30am	10:45am	null_no_attribute	...
5	CSI 2120	TuTh	11:00am	12:15pm	null_no_attribute	...
6	CSI 2120	TuTh	9:30am	10:45am	null_no_attribute	...
7	CSI 2107	TuTh	12:30pm	1:45pm	null_no_attribute	...

Table 26 – Continued

	Lecturer	TitleCode	Credits	GradeMethod	...
0	Harchol-Balter	null_no_attribute	null_no_attribute	null_no_attribute	...
1	Song	null_no_attribute	null_no_attribute	null_no_attribute	...
2	Wing	null_no_attribute	null_no_attribute	null_no_attribute	...
3	null_no_value	0101(13795)	(3 credits)	REG. CORE Capstone (CS) Course.	...
4	Memon	0201(13796)	(3 credits)	REG. CORE Capstone (CS) Course.	...
5	null_no_value	0301(13797)	(3 credits)	REG. CORE Capstone (CS) Course.	...
6	null_no_value	0101(14489)	(3 credits)	REG/AUD.	...
7	null_no_value	0101(14499)	(3 credits)	REG/AUD.	...

Table 26 – Continued

	Seats	Open	Waitlist
0	null_no_attribute	null_no_attribute	null_no_attribute
1	null_no_attribute	null_no_attribute	null_no_attribute
2	null_no_attribute	null_no_attribute	null_no_attribute
3	null_no_value	null_no_value	null_no_value
4	40	2	0
5	null_no_value	null_no_value	null_no_value
6	null_no_value	null_no_value	null_no_value
7	null_no_value	null_no_value	null_no_value

12 Benchmark Query 11: Attribute Name Does Not Define Semantics

Conflict: In this THALIA benchmark query, information on the instructors for the database course is requested. The given course data for this query is from Carnegie Mellon University and University

of California[16]. The challenge for the data integration system here is to handle the problem that the name of the attributes which provide instructor information do not adequately describe the meaning of the values which are stored there — i.e., these attributes are named according to the semester in which the particular instructor gives the respective lecture ("Fall 2003", "Winter 2004", etc.)

Source Data: See Table 3 (IConcept CarnegieMellonCSCourse), Table 4 (IConcept CarnegieMellonCSLecturer), Table 27 (IConcept UniCaliforniaCSCourse), and Table 28 (IConcept UniCaliforniaCSLecturer). Note that the course entitled "Database System Implementation" by the instructor called "Yannis" that is shown in [HST04] does not exist in the given course data from University of California.

Table 27: University of California Courses (IConcept UniCaliforniaCSCourse)

	Number	Title
0	CSE 200	Computability Complexity
1	CSE 201A	Advanced Complexity
2	CSE 202	Algorithms and Analysis
3	CSE 203A	Advanced Algorithms
4	CSE 204A	Combinatorial optimization
5	CSE 205A	Logic in Computer Science
6	CSE 206A	Lattice Algorithms and Applications
7	CSE 206B	Algorithms in Computational Biology
8	CSE 207	Modern Cryptography
9	CSE 208	Advanced Cryptography
10	CSE 209A	Top/Sem: Alg,Complexity Logic
11	CSE 209B	Top/Sem: Cryptography
12	CSE 210	Principles of Software Engineering
13	CSE 211	Software Testing Analysis
14	CSE 218	Adv Topics: Software Engineering
15	CSE 221	Operating Systems
16	CSE 222A	Computer Communication Networks
17	CSE 222B	Internet Algorithmics
18	CSE 223A	Principles of Distributed Systems
19	CSE 223B	Dist. Computing and Systems
20	CSE 224	Computer System Performance Evaluation
21	CSE 225	High Perf Dist Comptg Grids
22	CSE 226	Storage Systems
23	CSE 227	Computer Security
24	CSE 228	Multimedia Systems
25	CSE 229A	Top/Sem: Computer Systems
26	CSE 229B	Top/Sem: Networks Communication
27	CSE 229C	Top/Sem: Computer Security
28	CSE 230	Principles Programming Languages
29	CSE 231	Advanced Compiler Design
30	CSE 232	Principles of Data Base Systems
31	CSE 232B	Database System Implementation
32	CSE 233	Database Theory
33	CSE 237A	Intro to Embedded Computing

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	Number	Title
34	CSE 238	Topics Prog Lang Design Implem
35	CSE 240A	Principles of Computer Architecture
36	CSE 240B	Advanced Computer Architecture
37	CSE 241A	Intro to Computing Circuitry
38	CSE 242A	Integrated Circuit Layout Automation
39	CSE 243A	Synthesis Methodologies in VLSI CAD
40	CSE 244A	VLSI Test
41	CSE 244B	Testable Fault-Tolerant Hardware Des
42	CSE 245	Comp Aided Circuit Simulation Verif
43	CSE 246	Comp Arithmetic Algs Hardware Des
44	CSE 247	Applic Specific Reconfig Comp Arch
45	CSE 248	Alg Optimization Found VLSI CAD
46	CSE 249A	Top/Sem: Computer Architecture
47	CSE 249B	Top/Sem: VLSI
48	CSE 249C	Top/Sem: CAD
49	CSE 250A	Artificial Intelligence I
50	CSE 250B	Artificial Intelligence II
51	CSE 252A	Computer Vision
52	CSE 252B	Computer Vision II
53	CSE 252C	Selected Topics in Vision Learning
54	CSE 253	Neural Networks
55	CSE 254	Machine Learning
56	CSE 255	Intelligent Systems
57	CSE 256	Statistical Natural Lang Proc
58	CSE 257	Computational Biology
59	CSE 257A	Biomolecular Seq Structure Analy
60	CSE 258A	Connectionists Natural Language
61	CSE 259	Seminar Artificial Intellgnce
62	CSE 260	Parallel Computation
63	CSE 261	Parallel Distributed Computation
64	CSE 262	Sys Supp Appl Par Computing
65	CSE 267	Computer Graphics, New
66	CSE 268A	Topics in Parallel Computing
67	CSE 268C	Topics High-Performance Prog
68	CSE 269	Seminar Parallel Computing
69	CSE 270	Statistics Prob Manufacturing
70	CSE 271	User Intrface Des: Soc Tech Issues
71	CSE 272	Adv. Appearance Modeling
72	CSE 275	Social Aspects Tech. Science
73	CSE 268D	Social Aspects Tech Sci
74	CSE 290	Seminar in CSE
75	CSE 291	Topics in CSE
76	CSE 292	Faculty Research Seminar
77	CSE 294	Research Mtg: Systems Seminar
78	CSE 294	Research Mtg: Reliable Sys. Synthesis
79	CSE 294	Research Mtg: Database
80	CSE 294	Research Mtg: Meaning and Component
81	CSE 599	Teaching Methods in CS

Table 28: University of California Instructors (IConcept UniCaliforniaCSLecturer)

	Number	Name	Semester
0	CSE 200	-	Fall2003
1	CSE 200	Bellare	Winter2004
2	CSE 200	-	Spring2004
3	CSE 201A	-	Fall2003
4	CSE 201A	-	Winter2004
5	CSE 201A	Impagliazzo	Spring2004
6	CSE 202	Paturi (PhD)	Fall2003
7	CSE 202	Hu (MS)	Winter2004
8	CSE 202	Impagliazzo	Spring2004
9	CSE 203A	-	Fall2003
10	CSE 203A	Impagliazzo	Winter2004
11	CSE 203A	-	Spring2004
12	CSE 204A	-	Fall2003
13	CSE 204A	-	Winter2004
14	CSE 204A	Hu	Spring2004
15	CSE 205A	-	Fall2003
16	CSE 205A	-	Winter2004
17	CSE 205A	-	Spring2004
18	CSE 206A	-	Fall2003
19	CSE 206A	Micciancio	Winter2004
20	CSE 206A	-	Spring2004
21	CSE 206B	-	Fall2003
22	CSE 206B	-	Winter2004
23	CSE 206B	Pevzner	Spring2004
24	CSE 207	-	Fall2003
25	CSE 207	-	Winter2004
26	CSE 207	Bellare	Spring2004
27	CSE 208	-	Fall2003
28	CSE 208	-	Winter2004
29	CSE 208	Micciancio	Spring2004
30	CSE 209A	-	Fall2003
31	CSE 209A	-	Winter2004
32	CSE 209A	-	Spring2004
33	CSE 209B	-	Fall2003
34	CSE 209B	-	Winter2004
35	CSE 209B	-	Spring2004
36	CSE 210	-	Fall2003
37	CSE 210	-	Winter2004
38	CSE 210	Griswold	Spring2004
39	CSE 211	Cancelled	Fall2003
40	CSE 211	-	Winter2004
41	CSE 211	-	Spring2004
42	CSE 218	Griswold	Fall2003
43	CSE 218	Krueger	Winter2004
44	CSE 218	-	Spring2004
45	CSE 221	Voelker (PhD)	Fall2003
46	CSE 221	Savage (MS)	Fall2003
47	CSE 221	-	Winter2004
48	CSE 221	-	Spring2004

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	Number	Name	Semester
49	CSE 222A	-	Fall2003
50	CSE 222A	Vahdat	Winter2004
51	CSE 222A	-	Spring2004
52	CSE 222B	-	Fall2003
53	CSE 222B	-	Winter2004
54	CSE 222B	Canc	Spring2004
55	CSE 223A	-	Fall2003
56	CSE 223A	Marzullo	Winter2004
57	CSE 223A	-	Spring2004
58	CSE 223B	-	Fall2003
59	CSE 223B	-	Winter2004
60	CSE 223B	Snoeren	Spring2004
61	CSE 224	-	Fall2003
62	CSE 224	Pasquale	Winter2004
63	CSE 224	-	Spring2004
64	CSE 225	-	Fall2003
65	CSE 225	-	Winter2004
66	CSE 225	Chien	Spring2004
67	CSE 226	-	Fall2003
68	CSE 226	Burkhard	Winter2004
69	CSE 226	-	Spring2004
70	CSE 227	-	Fall2003
71	CSE 227	-	Winter2004
72	CSE 227	-	Spring2004
73	CSE 228	-	Fall2003
74	CSE 228	-	Winter2004
75	CSE 228	Rangan	Spring2004
76	CSE 229A	-	Fall2003
77	CSE 229A	-	Winter2004
78	CSE 229A	-	Spring2004
79	CSE 229B	-	Fall2003
80	CSE 229B	-	Winter2004
81	CSE 229B	-	Spring2004
82	CSE 229C	-	Fall2003
83	CSE 229C	-	Winter2004
84	CSE 229C	-	Spring2004
85	CSE 230	-	Fall2003
86	CSE 230	-	Winter2004
87	CSE 230	-	Spring2004
88	CSE 231	Ferrante	Fall2003
89	CSE 231	-	Winter2004
90	CSE 231	-	Spring2004
91	CSE 232	-	Fall2003
92	CSE 232	Yannis	Winter2004
93	CSE 232	-	Spring2004
94	CSE 232B	-	Fall2003
95	CSE 232B	-	Winter2004
96	CSE 232B	Deutsch	Spring2004
97	CSE 233	-	Fall2003
98	CSE 233	-	Winter2004

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	Number	Name	Semester
99	CSE 233	Vianu	Spring2004
100	CSE 237A	-	Fall2003
101	CSE 237A	-	Winter2004
102	CSE 237A	Gupta	Spring2004
103	CSE 238	-	Fall2003
104	CSE 238	-	Winter2004
105	CSE 238	-	Spring2004
106	CSE 240A	Calder	Fall2003
107	CSE 240A	Orailoglu	Winter2004
108	CSE 240A	-	Spring2004
109	CSE 240B	-	Fall2003
110	CSE 240B	-	Winter2004
111	CSE 240B	Calder	Spring2004
112	CSE 241A	-	Fall2003
113	CSE 241A	See ECE 260B	Winter2004
114	CSE 241A	-	Spring2004
115	CSE 242A	-	Fall2003
116	CSE 242A	-	Winter2004
117	CSE 242A	Cheng	Spring2004
118	CSE 243A	-	Fall2003
119	CSE 243A	Orailoglu	Winter2004
120	CSE 243A	-	Spring2004
121	CSE 244A	-	Fall2003
122	CSE 244A	Friedman	Winter2004
123	CSE 244A	-	Spring2004
124	CSE 244B	-	Fall2003
125	CSE 244B	-	Winter2004
126	CSE 244B	-	Spring2004
127	CSE 245	-	Fall2003
128	CSE 245	Cheng	Winter2004
129	CSE 245	-	Spring2004
130	CSE 246	-	Fall2003
131	CSE 246	Cheng	Winter2004
132	CSE 246	-	Spring2004
133	CSE 247	-	Fall2003
134	CSE 247	-	Winter2004
135	CSE 247	-	Spring2004
136	CSE 248	-	Fall2003
137	CSE 248	-	Winter2004
138	CSE 248	Kahng	Spring2004
139	CSE 249A	-	Fall2003
140	CSE 249A	-	Winter2004
141	CSE 249A	-	Spring2004
142	CSE 249B	-	Fall2003
143	CSE 249B	-	Winter2004
144	CSE 249B	-	Spring2004
145	CSE 249C	-	Fall2003
146	CSE 249C	-	Winter2004
147	CSE 249C	-	Spring2004
148	CSE 250A	-	Fall2003

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	Number	Name	Semester
149	CSE 250A	-	Winter2004
150	CSE 250A	-	Spring2004
151	CSE 250B	_	Fall2003
152	CSE 250B	-	Winter2004
153	CSE 250B	Dasgupta	Spring2004
154	CSE 252A	-	Fall2003
155	CSE 252A	Kriegman	Winter2004
156	CSE 252A	-	Spring2004
157	CSE 252B	-	Fall2003
158	CSE 252B	-	Winter2004
159	CSE 252B	Belongie	Spring2004
160	CSE 252C	Belongie	Fall2003
161	CSE 252C	-	Winter2004
162	CSE 252C	-	Spring2004
163	CSE 253	-	Fall2003
164	CSE 253	-	Winter2004
165	CSE 253	-	Spring2004
166	CSE 254	-	Fall2003
167	CSE 254	-	Winter2004
168	CSE 254	Elkan	Spring2004
169	CSE 255	-	Fall2003
170	CSE 255	-	Winter2004
171	CSE 255	-	Spring2004
172	CSE 256	-	Fall2003
173	CSE 256	-	Winter2004
174	CSE 256	Cottrell	Spring2004
175	CSE 257	-	Fall2003
176	CSE 257	-	Winter2004
177	CSE 257	-	Spring2004
178	CSE 257A	-	Fall2003
179	CSE 257A	Pevzner	Winter2004
180	CSE 257A	-	Spring2004
181	CSE 258A	-	Fall2003
182	CSE 258A	-	Winter2004
183	CSE 258A	-	Spring2004
184	CSE 259	Cottrell	Fall2003
185	CSE 259	Cottrell	Winter2004
186	CSE 259	Cottrell	Spring2004
187	CSE 260	Baden	Fall2003
188	CSE 260	-	Winter2004
189	CSE 260	-	Spring2004
190	CSE 261	-	Fall2003
191	CSE 261	-	Winter2004
192	CSE 261	-	Spring2004
193	CSE 262	-	Fall2003
194	CSE 262	-	Winter2004
195	CSE 262	-	Spring2004
196	CSE 267	-	Fall2003
197	CSE 267	-	Winter2004
198	CSE 267	-	Spring2004

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	Number	Name	Semester
199	CSE 268A	-	Fall2003
200	CSE 268A	-	Winter2004
201	CSE 268A	-	Spring2004
202	CSE 268C	-	Fall2003
203	CSE 268C	-	Winter2004
204	CSE 268C	-	Spring2004
205	CSE 269	-	Fall2003
206	CSE 269	-	Winter2004
207	CSE 269	-	Spring2004
208	CSE 270	-	Fall2003
209	CSE 270	-	Winter2004
210	CSE 270	-	Spring2004
211	CSE 271	-	Fall2003
212	CSE 271	-	Winter2004
213	CSE 271	Goguen	Spring2004
214	CSE 272	Jensen	Fall2003
215	CSE 272	-	Winter2004
216	CSE 272	-	Spring2004
217	CSE 275	Goguen	Fall2003
218	CSE 275	-	Winter2004
219	CSE 275	-	Spring2004
220	CSE 268D	-	Fall2003
221	CSE 268D	-	Winter2004
222	CSE 268D	-	Spring2004
223	CSE 290	-	Fall2003
224	CSE 290	-	Winter2004
225	CSE 290	-	Spring2004
226	CSE 291	Bafna, Genomic Alg.	Fall2003
227	CSE 291	Elkan	Winter2004
228	CSE 291	Ludaescer, Process Integration	Spring2004
229	CSE 292	Bafna	Fall2003
230	CSE 292	Jensen	Winter2004
231	CSE 292	-	Spring2004
232	CSE 294	Voelker	Fall2003
233	CSE 294	Snoeren	Winter2004
234	CSE 294	Staff	Spring2004
235	CSE 294	Orailoglu	Fall2003
236	CSE 294	Orailoglu	Winter2004
237	CSE 294	Staff	Spring2004
238	CSE 294	Deutsch	Fall2003
239	CSE 294	-	Winter2004
240	CSE 294	-	Spring2004
241	CSE 294	-	Fall2003
242	CSE 294	-	Winter2004
243	CSE 294	Goguen	Spring2004
244	CSE 599	Kube	Fall2003
245	CSE 599	Dasgupta	Fall2003
246	CSE 599	-	Winter2004

Conflict Resolution: In SIRUP, attribute names must accurately express the intended meaning of their values in order to enable correct integration results. Hence, the misleading attribute names are changed as part of the normalization process to ensure that proper source data is available for integration activities — see the "Name" and "Semester" attributes in Table 28. On this foundation, the current benchmark query can be addressed analogously to the previous case, i.e., by employing joins and and outer union to create integrated course records; then, all courses whose title contains "Database" can be determined for the requested result. This is shown in the following SIQL query:

Listing 19: SIQL Solution for THALIA Benchmark Query 11

```
0  select * from (
1          (select c.Code, c.Sec, CourseX−Listed, CourseTitle, Room, Day,
2          TimeBegin, TimeEnd, Units, Lecturer from
3                  (select * from CarnegieMellonCSCourse) as c
4                  inner join
5                  (select * from CarnegieMellonCSLecturer) as l
6                  on c.code = l.code and l.sec = c.sec)
7          outer union
8          (select c.Number as Code, Title as CourseTitle, Name as Lecturer,
9          Semester from (
10                 (select * from UniCaliforniaCSCourse) as c
11                 inner join
12                 (select * from UniCaliforniaCSLecturer) as l
13                 on c.Number = l.Number)) )
14 where matches(CourseTitle, "(.)*Database(.)*") = true;
```

Result: The requested information on the instructors for the database course is shown in the following table (see the "Lecturer" and "CourseTitle" attributes):

Table 29: Result Data for SIQL Query from Listing 19

	Code	Sec	CourseX-Listed	CourseTitle	...
0	15-721*	A	.	Database System Design and Implementation	...
1	CSE 232B	null_no_attribute	null_no_attribute	Database System Implementation	...
2	CSE 232B	null_no_attribute	null_no_attribute	Database System Implementation	...
3	CSE 232B	null_no_attribute	null_no_attribute	Database System Implementation	...
4	CSE 233	null_no_attribute	null_no_attribute	Database Theory	...
5	CSE 233	null_no_attribute	null_no_attribute	Database Theory	...
6	CSE 233	null_no_attribute	null_no_attribute	Database Theory	...
7	CSE 294	null_no_attribute	null_no_attribute	Research Mtg: Database	...
8	CSE 294	null_no_attribute	null_no_attribute	Research Mtg: Database	...
9	CSE 294	null_no_attribute	null_no_attribute	Research Mtg: Database	...
10	CSE 294	null_no_attribute	null_no_attribute	Research Mtg: Database	...
11	CSE 294	null_no_attribute	null_no_attribute	Research Mtg: Database	...
12	CSE 294	null_no_attribute	null_no_attribute	Research Mtg: Database	...
13	CSE 294	null_no_attribute	null_no_attribute	Research Mtg: Database	...
14	CSE 294	null_no_attribute	null_no_attribute	Research Mtg: Database	...
15	CSE 294	null_no_attribute	null_no_attribute	Research Mtg: Database	...
16	CSE 294	null_no_attribute	null_no_attribute	Research Mtg: Database	...

Table 29 – Continued

	Room	Day	TimeBegin	TimeEnd	...
0	WeH 4615A	MWF	1:30pm	2:50pm	...
1	null_no_attribute	null_no_attribute	null_no_attribute	null_no_attribute	...
2	null_no_attribute	null_no_attribute	null_no_attribute	null_no_attribute	...
3	null_no_attribute	null_no_attribute	null_no_attribute	null_no_attribute	...
4	null_no_attribute	null_no_attribute	null_no_attribute	null_no_attribute	...
5	null_no_attribute	null_no_attribute	null_no_attribute	null_no_attribute	...
6	null_no_attribute	null_no_attribute	null_no_attribute	null_no_attribute	...
7	null_no_attribute	null_no_attribute	null_no_attribute	null_no_attribute	...
8	null_no_attribute	null_no_attribute	null_no_attribute	null_no_attribute	...
9	null_no_attribute	null_no_attribute	null_no_attribute	null_no_attribute	...
10	null_no_attribute	null_no_attribute	null_no_attribute	null_no_attribute	...
11	null_no_attribute	null_no_attribute	null_no_attribute	null_no_attribute	...
12	null_no_attribute	null_no_attribute	null_no_attribute	null_no_attribute	...
13	null_no_attribute	null_no_attribute	null_no_attribute	null_no_attribute	...
14	null_no_attribute	null_no_attribute	null_no_attribute	null_no_attribute	...
15	null_no_attribute	null_no_attribute	null_no_attribute	null_no_attribute	...
16	null_no_attribute	null_no_attribute	null_no_attribute	null_no_attribute	...

Table 29 – Continued

	Units	Lecturer	Semester
0	12	Ailamaki	null_no_attribute
1	null_no_attribute	-	Fall2003
2	null_no_attribute	-	Winter2004
3	null_no_attribute	Deutsch	Spring2004
4	null_no_attribute	-	Fall2003
5	null_no_attribute	-	Winter2004
6	null_no_attribute	Vianu	Spring2004
7	null_no_attribute	-	Fall2003
8	null_no_attribute	-	Spring2004
9	null_no_attribute	-	Winter2004
10	null_no_attribute	Deutsch	Fall2003
11	null_no_attribute	Goguen	Spring2004
12	null_no_attribute	Orailoglu	Fall2003
13	null_no_attribute	Orailoglu	Winter2004
14	null_no_attribute	Snoeren	Winter2004
15	null_no_attribute	Staff	Spring2004
16	null_no_attribute	Voelker	Fall2003

13 Benchmark Query 12: Attribute Composition

Conflict: In the last THALIA query, information on the title and time for computer networks courses is requested. The given course data for this query is from Carnegie Mellon University and Brown University. The challenge for the data integration system here is to determine that course title, day, and time information in the catalog of Brown University are represented as part of the title attribute, rather than as separate attributes.

Source Data: See Table 3 (IConcept CarnegieMellonCSCourse), Table 4 (IConcept CarnegieMellonCSLecturer), and Table 11 (IConcept BrownUniCSCourse).

Conflict Resolution: Based on the normalizations of composite and set-oriented values, this benchmark query can be handled analogously to previous benchmark queries. That is, by use of a join and an outer union, integrated records can be created which are then checked whether their title contains the character sequence "Computer Networks" in to determine the relevant courses for the current benchmark query. This is shown in the following SIQL query:

Listing 20: SIQL Solution for THALIA Benchmark Query 12

```
0  select * from (
1          (select c.Code, c.Sec, CourseX−Listed, CourseTitle, Room, Day,
2          TimeBegin, TimeEnd, Units, Lecturer from
3                  (select * from CarnegieMellonCSCourse) as c
4                  inner join
5                  (select * from CarnegieMellonCSLecturer) as l
6                  on c.code = l.code and l.sec = c.sec)
7          outer union
8          (select Code, InstructorURL, Instructor as Lecturer,
9          CourseURL, Title as CourseTitle, HoursType, Days as Day,
10         TimeBegin, TimeEnd, Room from BrownUniCSCourse) )
11 where matches(CourseTitle, "(.)∗Computer Networks(.)∗") = true;
```

Result: The requested information on the title and time for computer networks courses is shown in the following table (note the "CourseTitle", "TimeBegin", and "TimeEnd" attributes):

Table 30: Result Data for SIQL Query from Listing 20

	Code	Sec	CourseX-Listed	CourseTitle	Room	...
0	15-744*	A	.	Computer Networks	WeH 5409	...
1	CS168	null_no_attribute	null_no_attribute	Computer Networks	CIT 368	...

Table 30 – Continued

	Day	TimeBegin	TimeEnd	Units	Lecturer	...
0	F	1:30pm	4:20pm	12	Zhang	...

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	Day	TimeBegin	TimeEnd	Units	Lecturer	...
1	M	3pm	5:30pm	null_no_attribute	Doeppner	...

Table 30 – Continued

	InstructorURL	CourseURL	HoursType
0	null_no_attribute	null_no_attribute	null_no_attribute
1	http://www.cs.brown.edu/∼twd/	http://www.cs.brown.edu/courses/cs168/	M hr.

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