دانشگاه آزاد اسلامی واحد تبریز

نام درس: روش های رسمی در مهندسی نرم افزار

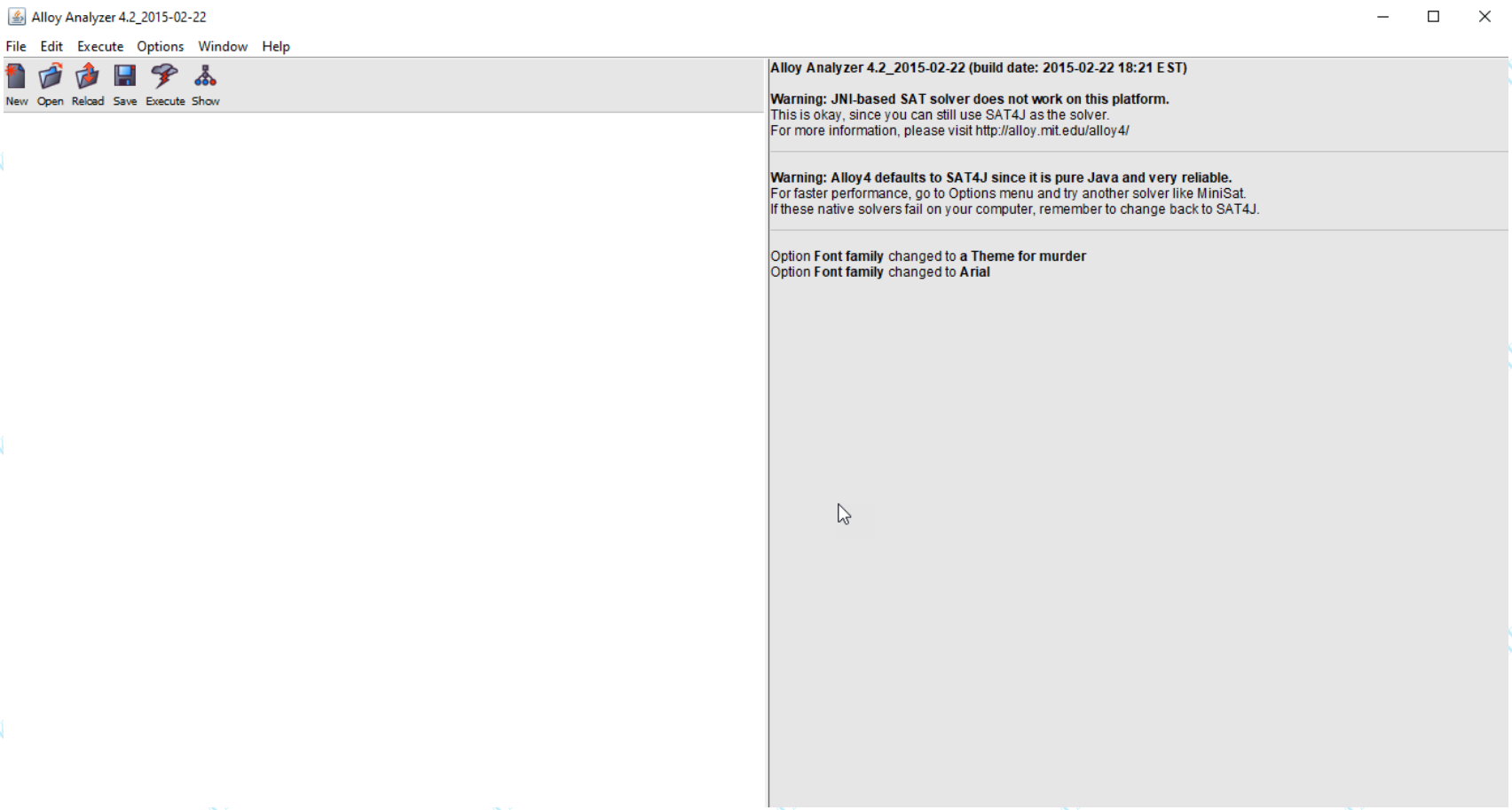
بخش: ابزار Alloy

نام استاد: دکتر مسعود کارگر

Alloy tools

- Alloytools.org

Alloy tools


Alloy Analyzer 4.2_2015-02-22
File Edit Execute Options Window Help
New Open Reload Save Execute Show
Alloy Analyzer 4.2_2015-02-22 (build date: 2015-02-22 18:21 EST)
Warning: JNI-based SAT solver does not work on this platform.
This is okay, since you can still use SAT4J as the solver.
For more information, please visit http://alloy.mit.edu/alloy4/
Warning: Alloy4 defaults to SAT4J since it is pure Java and very reliable.
For faster performance, go to Options menu and try another solver like MiniSat.
If these native solvers fail on your computer, remember to change back to SAT4J.
Option Font family changed to a Theme for murder
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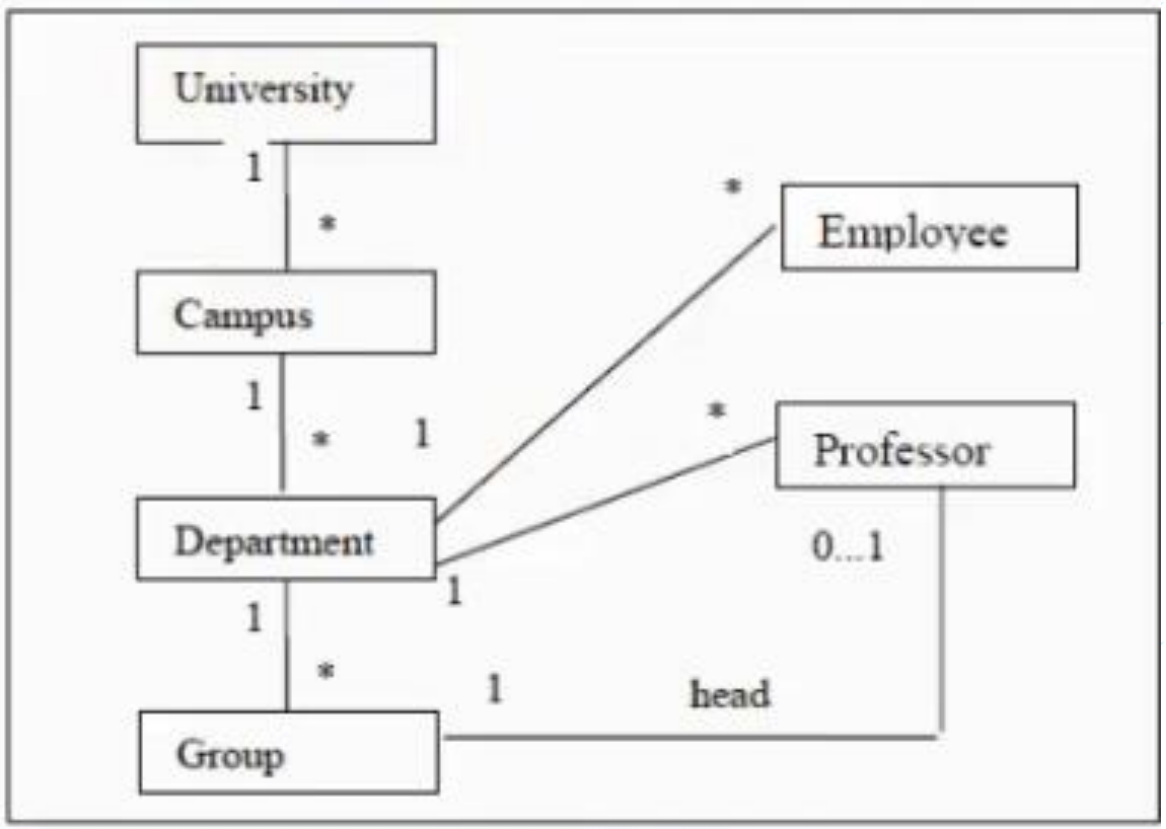

University
1
*
Campus
1
*
1
Department
1
*
Group
*
Employee
*
Professor
0...1
1
head

Example in alloy

```
module university
sig university{
chairman:one professore,
research: one professore,
education: one professore
}

sig campus{
belongsto:one university,
chairman:one professore,
research: one professore,
education: one professore
}

sig department{
chairman:one professore,
research: one professore,
education: one professore
}
```

```
sig group{
head: one professore
}

sig professore{
worksat: one group,
member: one group
}

sig student {
studiesat: one group
}

sig employee{
worksat:one group
}

pred show(){}
run show
```

Abstract in model

```
module university
abstract sig educationalunit{
chairman:one professore,
research: one professore,
education: one professore
}


sig university extends educationalunit  {
}

sig campus  extends educationalunit{
belongsto:one university
}


sig department  extends educationalunit{
}
```

```
sig group{
head: one professore
}


sig professore{
worksat: one group,
member: one group
}

sig student {
studiesat: one group
}

sig employee{
worksat:one group
}

pred show(){}
run show
```

“Academia” Modeling Example

- We will model an academic enterprise expressing relationships between
  - People
    - Faculty
    - Students
      - Graduate
      - Undergraduate
    - Instructors – which can be grad students or faculty
  - Courses
  - Academic departments
  - Personal ID numbers

How should we model these basic domains in Alloy?

Strategy

– • Build and validate your model incrementally

  –Start with basic signatures and fields
  –Add basic constraints
  –Instantiate the model and study the results
  –Probe the model with assertions

Strategy

- • Add groups of features at a time
  - –New signatures and fields
  - –New constraints
  - –Confirm previous assertions
  - –Probe new features with assertions

Basic Components

- People
  - Students: Undergrads and Grads
  - Instructors: Faculty and Grads
- Courses
- Relationships
  - One instructor teaches a course
  - One or more students are taking a course
  - Students can be waiting for course

Academia Signatures

```
abstract sig Person {}
sig Faculty extends Person {}
abstract sig Student extends Person {}
sig Graduate, Undergrad extends Student {}
sig Instructor in Person {}

sig Course {}
...
```

We are not specifying here that instructors can only be graduate students or faculty. We will do that later with a "fact" constraint.

Academia Fields

– One instructor teaches a course
  • 2 choices:

```
sig Instructor in Person {
  teaches: Course
}
fact oneInstrucPerCourse {
  all c:Course | one teaches.c
}

sig Course {
  taughtby: one Instructor }
```

We cannot specify that there is exactly one instructor per course

We have to add a fact specifying this constraint

Course Fields

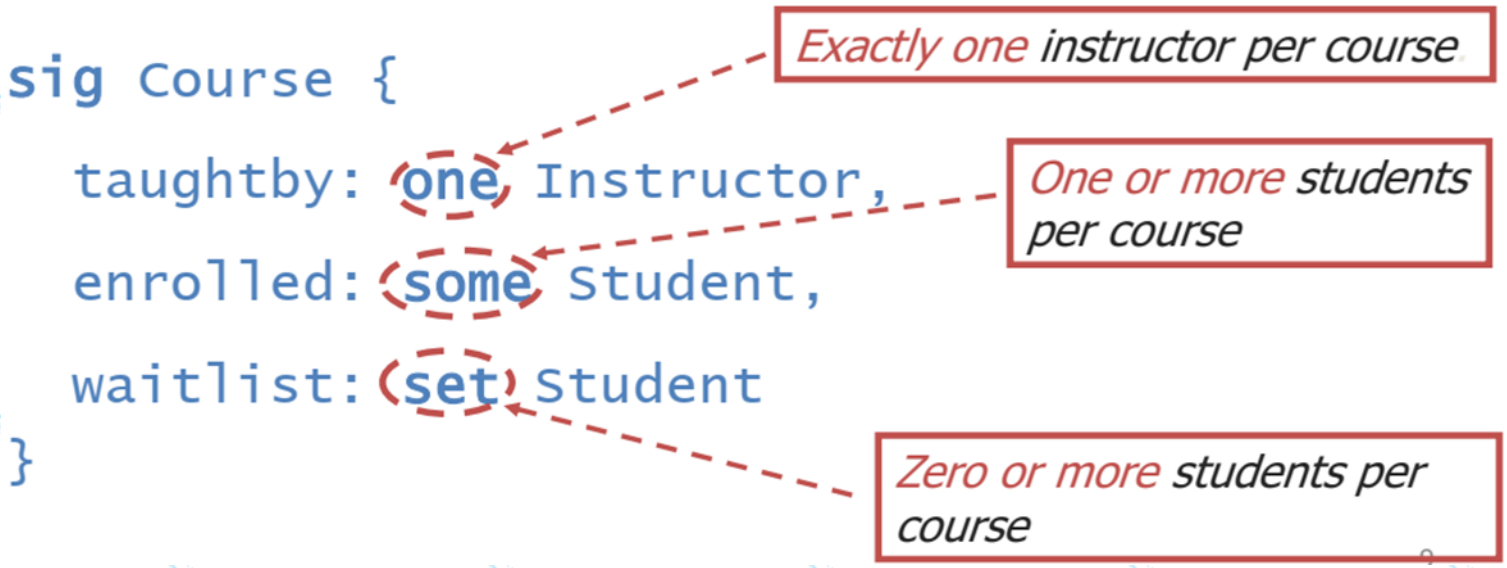
– One instructor teaches a course

• One or more students are taking a course

– • Students can be waiting for course

Course Fields

- One instructor teaches a course
- One or more students are taking a course
- Students can be waiting for course



More relations

- We may choose to define auxiliary relations:

  `teaches` (transpose of `taughtby`)
  `taking` (transpose of `enrolled`)
  `waitingfor` (transpose of `waitlist`)

```
fun teaches: Instructor -> Course { ~taughtby }
fun taking: Student -> Course { ~enrolled }
fun waitingfor: Student -> Course { ~waitlist }
```

- Or not:

  if `i` is an instructor, then

  `i.teaches <=> taughtby.i`

Note

- • Let i be an Instructor
  • Let taughtby be the following binary relation
  - taughtby: Course -> one Instructor
- • The following expressions are equivalent and give a set of courses as result
  - taugthby.i
  - i.~taugthby
  - i[taugthby]

Academia Constraints

- All instructors are either faculty or graduate students

  Was not expressed in set definition--although it could have, with

```
sig Instructor in Graduate + Faculty
```

- No one is waiting for a course unless someone is enrolled

- No graduate students teach a course that they are enrolled in

Academia Constraints

```
fact {
  -- All instructors are either Faculty or Graduate Students


  -- no one is waiting for a course unless someone is enrolled
  -- (This is actually superfluous. Why?)



  -- graduate students do not teach courses they are enrolled in
     or waiting to enroll in
```

Academia Constraints

```
fact {
  -- All instructors are either Faculty or Graduate Students
  all i: Instructor | i in Faculty + Graduate

  -- no one is waiting for a course unless someone is enrolled
  -- (This is actually superfluous. Why?)
  all c: Course |
      some c.waitlist => some c.enrolled

  -- graduate students do not teach courses they are enrolled in
     or waiting to enroll in
  all c: Course |
      c.taughtby !in c.enrolled + c.waitlist
```

Academia Realism Constraints

- There is a graduate student who is an instructor
- There are at least:
  - Two courses and
  - Three undergraduates

Academia Realism Constraints

Can be added to the model as facts, or just put in a run command to instruct the Alloy Analyzer to ignore unrealistic instances

```
pred RealismConstraints [] {
   -- there is a graduate student who is an instructor
   some Graduate & Instructor

   -- there are at least two courses
   #Course > 1

   -- there are at least three undergraduates
   #Undergrad > 2
}
```

Academia Assertions

Let’s check if our model has these properties:

- No instructor is on the waitlist for a course that he/she teaches
- No student is enrolled and on the waitlist for the same course

Academia Assertions

-- no instructor is on the waitlist for a course that he/she teaches

-- no student is enrolled and on the waitlist for the same course

Academia Assertions

```
-- no instructor is on the waitlist for a course that he/she teaches
assert NoWaitingTeacher {
  all c: Course |
          no (c.taughtby & c.waitlist)
}

-- no student is enrolled and on the waitlist for the same course
assert NoEnrolledAndWaiting {
  all c: Course |
          no (c.enrolled & c.waitlist)
}
```

Exercises

- Load academia-1.als
- With realism conditions enabled, do any instances exist in the default scopes?
  - Manipulate the scopes as necessary to obtain an instance under the realism conditions
- By looking at various sample instances, do you consider the model to be underconstrained in any way?
- Check assertions

Realism constraints

- • No instances exist in the default scope
-
  • Why ?
-
  - default scope:
    at most 3 tuples in each top-level signature
-
  - entails: at most 3 Students
-
  - some Graduate & Instructor
    #Undergrad > 2
-
  - entails: at least 4 Students

Realism Constraints

```
pred [] RealismConstraints
{
   -- there is a graduate student who's an instructor
   some Graduate & Instructor

   -- there are at least two courses
   #Course > 1

   -- there are at least three undergraduates
   #Undergrad > 2
}

run RealismConstraints for 4
```

Instance

~~#Undergrad > 2~~ #Undergrad > 1

```
Instance found:

Signatures:
  Course = {C0,C1}
  Person = {U0,U1,G}
  Faculty = {}
  Student = {U0,U1,G}
  Undergrad = {U0,U1}
  Graduate = {G}
  Instructor = {G}

Relations:
  taughtby = {(C0,G),(C1,G)}
  enrolled = {(C0,U1),(C1,U0)}
  waitlist = {(C1,U1),(C1,U0)}
```

Need to relate enrollment and waiting lists

Counter-example to assertion

```
Analyzing NoEnrolledAndWaiting ...

Counterexample found:

Signatures:
  Course = {C}
  Person = {G0,G1,F}
  Faculty = {F}
  Student = {G0,G1}
  Undergrad = {}
  Graduate = {G0,G1}
  Instructor = {G0,G1}

Relations:
  taughtby = {(C,G0)}
  enrolled = {(C,G1)}
  waitlist = {(C,G1)}
```

Academia Assertions

- No student is enrolled and on the waitlist for the same course
  - A counterexample has been found, hence we transform this assertion into a fact
- No instructor is on the waitlist for a course that he/she teaches
  - No counterexample

Academia Assertions

- NoWaitingTeacher assertion
  - No counterexample within the default scope
  - No counterexample within the scope 4, 5, 6, 10

- Can we conclude that the assertion is valid?
  - No! (It might have conterexamples but out of scope)

- But we take comfort in the
  - small scope hypothesis: if an assertion is not valid, it probably has a small counter-example

Why NoWaitingTeacher holds

- Assertion

```
-- no instructor is on the waitlist for a course that he/she teaches
assert NoWaitingTeacher {
  all c: Course | no (c.taughtby & c.waitlist)
}
```

- Facts

```
-- (i) faculty are not students and (ii) graduate students do not
-- teach courses they are enrolled in or waiting to enroll in
all c: Course |
  c.taughtby !in c.enrolled + c.waitlist
```

Extension 1

- Add an attribute for students
  - Unique ID numbers
  - This requires a new signature

- Add student transcripts
- Add prerequisite structure for courses

New Relations

```
sig Id {}
abstract sig Student extends Person {
  id: one Id,
  transcript: set Course
}
sig Graduate, Undergrad extends Student {}
sig Instructor in Person {}
sig Course {
  taughtby: one Instructor,
  enrolled: some Student,
  waitlist: set Student,
  prerequisites: set Course
}
```

New Constraints

- Each Student is identified by one unique ID
  - Exactly one ID per Student
    already enforced by multiplicities
  - No two distinct students have the same ID
    has to be specified as a fact

- A student's transcript contains a course only if it contains the course's prerequisites

- A course does not have itself as a prerequisite

- Realism: there exists a course with prerequisites and with students enrolled

Academia Constraints

```
fact {
  ...
  -- A student's transcript contains a course only
  -- if it contains the course's prerequisites
  all s: Student |
       s.transcript.prerequisites in s.transcript

  -- A course does not have itself as a prerequisite
  all c: Course | c !in c.prerequisites
}

run {
  ...
  -- there is a course with prerequisites and
  -- enrolled students
  some c: Course |
       some c.prerequisites and some c.enrolled
}
```

not sufficient!

Academia Constraints

```
fact {
  ...
   -- A student's transcript contains a course only
   -- if it contains the course's prerequisites
   all s: Student |
        s.transcript.prerequisites in s.transcript

   -- There are no cycles in the prerequisite dependencies
   all c: Course | c !in c.^prerequisites
}
run {
   ...
   -- there is a course with prerequisites and
   -- enrolled students
   some c: Course |
        some c.prerequisites and some c.enrolled
}
```

Academia Assertions

- Students can only wait to be in a course for which they already have the prerequisites

```
assert AllWaitsHavePrereqs {
  all s: Student |
     (waitlist.s).prerequisites in s.transcript
}
```

Exercises

- • Load academia-2.als
-
  - • With realism conditions enabled, do any instances exist in the default scopes?
    - – Manipulate the scopes as necessary to obtain an instance under the realism conditions
-
  - • By looking at various sample instances, do you consider the model to be underconstrained in any way?

Counter-example

```
Analyzing AllWaitsHavePrereqs ...
Counterexample found:
Signatures:
  Id = {Id0,Id1,Id2}
  Course = {C0,C1}
  Person = {U,G0,G1}
  Faculty = {}
  Student = {U,G0,G1}
  Undergrad = {U}
  Graduate = {G0,G1}
  Instructor = {G0,G1}
Relations:
  taughtby = {(C0,G0),(C1,G0)}
  enrolled = {(C0,U),(C1,G1)}
  waitlist = {(C1,U)}
  prerequisites = {(C1,C0)}
  transcript = {(G1,C0)}
  id = {(U,Id0),(G0,Id2),(G1,Id1)}
```

U waits for the course C1
and
C0 is a prerequisite for C1
but
U does not have C0

Where is (U,C0)?

New constraint

- • Old Assertion AllWaitsHavePrereqs
  Students can wait only for those courses for which they already have the prerequisites
-
  • Old Fact
  Students can have a course only if they already have the prerequisites
-
  • New Fact
  Students can have, wait for or take a course only if they already have the prerequisites

New constraint

- New Fact: A student can have, wait for or take a course only if they already have the prerequisites

```
all s: Student |
  (waitlist.s.prerequisites +
   enrolled.s.prerequisites +
   s.transcript.prerequisites)
  in s.transcript

all s: Student |
  (
   waitlist.s + enrolled.s + s.transcript
  ).prerequisites in s.transcript
```

Extension 2

- Add Departments, with
  - Instructors
  - Courses
  - Required courses
  - Student majors

- Add Faculty-Grad student relationships
  - Advisor
  - Thesis committee

Department Relations

- Each instructor is in a single department
  - Each department has at least one instructor
- Each department has some courses
  - Courses are in a single department
- Each student has a single department as his/her major

Faculty-Student Relations

- A *graduate* student has exactly one *faculty* member as an *advisor*

- *Faculty* members serve on *graduate* students' *committees*

New Relations

```
sig Faculty extends Person {
  incommittee: set Graduate
}

abstract sig Student extends
Person {
   major: one Department
}

sig Graduate extends Student {
  advisor: one Faculty
}
```

```
sig Instructor in Person {
  department:
    one Department
}

sig Department {
  course: some Course,
  required: some course
}
```

```
----------------------- Facts -----------------------

  -- Each department has at least one instructor
  all d: Department | some department.d

  -- Each course is in a single department
  all c: Course | one course.c
```

New Constraints

- Advisors are on their advisees' committees
- Students are advised by faculty in their major
- Only faculty can teach required courses
- Faculty members only teach courses in their department
- Required courses for a major are a subset of the courses in that major
- Students must be enrolled in at least one course from their major

Exercise

- Express as an Alloy fact each of the new constraints in the previous slide

Advisors are on their advisees' committees

```
------------------ Signatures and Fields -----------------
abstract sig Person {}
sig Faculty extends Person {
  incommittee: set Graduate
}
abstract sig Student extends
Person {
  id: one Id,
  transcript: set Course,
  major: one Department
}
sig Undergrad extends Student {}
sig Graduate extends Student {
  advisor: one Faculty
}
```

```
sig Instructor in Person {
  department: one Department
}
sig Course {
  taughtby: one Instructor,
  enrolled: some Student,
  waitlist: set Student,
  prerequisites: set Course
}
sig Id {}
sig Department {
  courses: some Course,
  required: some Course
}
```

Students are advised by faculty in their major

```
------------------ Signatures and Fields -----------------
abstract sig Person {}
sig Faculty extends Person {
  incommittee: set Graduate
}
abstract sig Student extends
Person {
  id: one Id,
  transcript: set Course,
  major: one Department
}
sig Undergrad extends Student {}
sig Graduate extends Student {
  advisor: one Faculty
}
sig Instructor in Person {
  department: one Department
}
sig Course {
  taughtby: one Instructor,
  enrolled: some Student,
  waitlist: set Student,
  prerequisites: set Course
}
sig Id {}
sig Department {
  courses: some Course,
  required: some Course
}
```

Required courses for a major are a subset of the courses in that major

```
------------------ Signatures and Fields -----------------
abstract sig Person {}
sig Faculty extends Person {
  incommittee: set Graduate
}
abstract sig Student extends
Person {
  id: one Id,
  transcript: set Course,
  major: one Department
}
sig Undergrad extends Student {}
sig Graduate extends Student {
  advisor: one Faculty
}
sig Instructor in Person {
  department: one Department
}
sig Course {
  taughtby: one Instructor,
  enrolled: some Student,
  waitlist: set Student,
  prerequisites: set Course
}
sig Id {}
sig Department {
  courses: some Course,
  required: some Course
}
```

Only faculty teach required courses

```
------------------ Signatures and Fields -----------------
abstract sig Person {}
sig Faculty extends Person {
  incommittee: set Graduate
}
abstract sig Student extends
Person {
  id: one Id,
  transcript: set Course,
  major: one Department
}
sig Undergrad extends Student {}
sig Graduate extends Student {
  advisor: one Faculty
}
sig Instructor in Person {
  department: one Department
}
sig Course {
  taughtby: one Instructor,
  enrolled: some Student,
  waitlist: set Student,
  prerequisites: set Course
}
sig Id {}
sig Department {
  courses: some Course,
  required: some Course
}
```

Faculty members only teach courses in their department

```
------------------- Signatures and Fields -------------------
abstract sig Person {}
sig Faculty extends Person {
  incommittee: set Graduate
}
abstract sig Student extends
Person {
  id: one Id,
  transcript: set Course,
  major: one Department
}
sig Undergrad extends Student {}
sig Graduate extends Student {
  advisor: one Faculty
}
```

```
sig Instructor in Person {
  department: one Department
}
sig Course {
  taughtby: one Instructor,
  enrolled: some Student,
  waitlist: set Student,
  prerequisites: set Course
}
sig Id {}
sig Department {
  courses: some Course,
  required: some Course
}
```

Students must be enrolled in at least one course from their major

```
------------------ Signatures and Fields -----------------
abstract sig Person {}
sig Faculty extends Person {
  incommittee: set Graduate
}
abstract sig Student extends
Person {
  id: one Id,
  transcript: set Course,
  major: one Department
}
sig Undergrad extends Student {}
sig Graduate extends Student {
  advisor: one Faculty
}
```

```
sig Instructor in Person {
  department: one Department
}
sig Course {
  taughtby: one Instructor,
  enrolled: some Student,
  waitlist: set Student,
  prerequisites: set Course
}
sig Id {}
sig Department {
  courses: some Course,
  required: some Course
}
```

There are at least two departments and some required courses

```
------------------ Signatures and Fields -----------------
abstract sig Person {}
sig Faculty extends Person {
  incommittee: set Graduate
}
abstract sig Student extends
Person {
  id: one Id,
  transcript: set Course,
  major: one Department
}
sig Undergrad extends Student {}
sig Graduate extends Student {
  advisor: one Faculty
}
sig Instructor in Person {
  department: one Department
}
sig Course {
  taughtby: one Instructor,
  enrolled: some Student,
  waitlist: set Student,
  prerequisites: set Course
}
sig Id {}
sig Department {
  courses: some Course,
  required: some Course
}
```

A student's committee members are faculty in his/her major

```
------------------ Signatures and Fields -----------------
abstract sig Person {}
sig Faculty extends Person {
  incommittee: set Graduate
}
abstract sig Student extends
Person {
  id: one Id,
  transcript: set Course,
  major: one Department
}
sig Undergrad extends Student {}
sig Graduate extends Student {
  advisor: one Faculty
}
sig Instructor in Person {
  department: one Department
}
sig Course {
  taughtby: one Instructor,
  enrolled: some Student,
  waitlist: set Student,
  prerequisites: set Course
}
sig Id {}
sig Department {
  courses: some Course,
  required: some Course
}
```

Assertions

- Realism constraints: There are at least two departments and some required courses

- Assertion: A student's committee members are faculty in his/her major

Exercises

- Load academia-3.als
- With realism conditions enabled, do any instances exist in the default scopes?
- Manipulate the scopes as necessary to obtain an instance under the realism conditions
  - This requires some thought since constraints may interact in subtle ways
  - For example, adding a department requires at least one faculty member for that department
- Can you think of any more questions about the model?
  - Formulate them as assertions and see if the properties are already enforced by the constraints