Domain Specific Languages

COMP 520: Compiler Design (4 credits)
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Designing Domain-Specific Languages (DSLs)

- Specialize language for domain-specific task.
- Avoid the urge to include all of your favourite language constructs.
- Make the language easy to use for the domain specialist.
- Decide on the right data and control abstractions.
- Try to reduce excess notation - are type declarations necessary?
- Ensure that you will be able to generate “efficient-enough” code for each construct.
- Decide whether a DSL or a specialized library is a better solution.
- Decide on the target language - aim for portability.
- Consider interfacing with a known host language in order to leverage existing libraries and for developing DSL libraries.
OncoTime is an experimental DSL for a real problem

- The real problem is designing a DSL which allows for easily analyzing, verifying and visualizing patient treatment paths in radiation oncology.

- OncoTime design motivated by real problems currently being solved “by hand coding” in the HIG group.

- Since the language is experimental, groups will be allowed to make small modifications and additions to the OncoTime language. All such modifications/additions should be documented and justified.

- Since the language is addressing a real problem, the projects may be prototypes of a system that is eventually used.
Radiation Oncology at the MUHC

- Radiation Oncology is the use of radiation to treat cancer and other diseases.

- About 1 in 3 people in the western world will develop cancer in their lifetime, and about half of those will require radiation. [http://ranzcr.edu.au/about/radiation-oncology](http://ranzcr.edu.au/about/radiation-oncology).

- Radiation Oncology in MUHC currently centered at MGH, but soon to move to the new cancer centre at the Glen site.

- Last year they treated 2,500 patients for a total of 40,000 treatments.

- The entire operation of the radiation oncology department is computerized, with a database containing complete information about treatments, documents, appointments and so on.

- For our project we have access to an anonymized version of the key parts of the database, so we will be able to use the OncoTime compilers to compile OncoTime programs which compute real, and potentially useful information.
A typical patient pathway through radiation oncology treatment

For a video and link to the patient information brochure, please visit http://muhc.ca/cancer/radiation-oncology. This should give you some idea of the process the patient goes through.
Patient Treatments

- Patient treatments are given every weekday, often for many weeks. For example, 5 weeks (25 treatments) is common for breast cancer.

- Each week the patient also has an appointment with his/her radiation oncologist, and may have other appointments with other medical professionals, such as nutritionists.

- For each appointment there are several times. The patient scans their medicare card when they arrive, this is the *arrival time*. Then when the patient is moved to the consultation room this gives us the *actual consult start time*. Each appointment also has a *scheduled start time*. One could imagine that there are many interesting questions to ask about waiting times for patients.
Time Series View of the Data

• You will note that the entire process is described as a series of events, ordered by time of the event.

• From the patient perspective, this series of events is also how they see the process.

• We would like to compute over the time series to ask questions such as:
  – What are all the events, ordered by time, for patient \( P \)?
  – How many (Which) consults were performed on breast cancer patients in January?
  – How many (Which) consults led to a ROR (RadOnc Requistion)?
  – What is the expected delay between CT Scan and Ready for Treatment?
  – How long has patient \( P \) been waiting for previous consultations?
  – Do Dr. \( D \)’s patients wait longer than average for planning and/or appointments?
  – Do patients wait longer on Monday mornings?
  – How many (Which) patients check-in more than 1 hour early?
  – Does checking in early result in being seen early?
  – How many patients who have finished treatments have the End of Treatment note finished within two weeks?
Filtering Data

• Many of the questions we want to ask are relevant only to part of the data, for example:
  – We may be interested only in certain time periods: between given dates, only Mondays, only the mornings.
  – We may only want to look at events relevant to patients with a specific diagnosis (i.e. breast cancer, prostate cancer, lung cancer, ...).
  – We may only want to look at some of the patients: only men, only patients born between 1990 and now, only patients from a specific postal code, only patient $P$, ...
Waiting Time for Planning

- Look at the time for planning for patients who had six essential events, in the correct order, **CT-SIM**, Ready for MD Contour, Ready for Dosimetry, Prescription Approved, Ready for Physics QA, and Ready for Treatment.

- Visualize the data in many different ways.

- Eventually develop a predictor, which can fairly accurately determine the expected number of days before the patient can begin treatment, based on many factors.
Waiting time for Consults

- Patients also come for many different types of appointments, including the initial consult, weekly consultations during treatments, and follow-up consults.

- It is interesting to study the waiting time for these patients, in order to better predict the expected waiting time, and to identify undesirable situations, such as patients arriving much too early, doctors scheduling too many patients during some time periods, and patients who are habitually late.
Average wait time per doctor with different metrics

- **Scheduled**
- **Adjusted**
- **Arrival**
<table>
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<tr>
<th>Monday, November 3, 20146</th>
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<tr>
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<td>Monday, November 3, 201414</td>
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<tr>
<td>Monday, November 3, 201415</td>
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</tr>
<tr>
<td>Monday, November 3, 201416</td>
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</table>
How is the data stored?

- The production database, Aria, is very large and complex.
- We are going to use a much simpler MySQL database.
- Events are encoded implicitly in the MySQL database.
- Previous studies have combined SQL queries with some post-processing.
- There are many ways of encoding similar values, and we need some way of grouping them (these groups were called aliases in a related project, http://scitation.aip.org/content/aapm/journal/medphys/41/8/10.1118/1.4894911).
<table>
<thead>
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<td>2</td>
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<tr>
<td>3</td>
<td>2</td>
<td>Consult R-I</td>
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<tr>
<td>4</td>
<td>2</td>
<td>Consult N-I</td>
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<td>5</td>
<td>2</td>
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<td>2</td>
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<td>2</td>
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<td>2</td>
<td>CONSULT NEW OUT</td>
</tr>
<tr>
<td>9</td>
<td>2</td>
<td>CONSULT NEW OUT PALLIATIVE</td>
</tr>
<tr>
<td>10</td>
<td>2</td>
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<tr>
<td>404</td>
<td>383</td>
<td>21926</td>
</tr>
</tbody>
</table>
How to design OncoTime?

- Want to support an abstraction of time series of events, because this corresponds to our conceptual model of the process.

- Want a way of easily creating groups of related values.

- Need to get the correct data out of the MySQL database, but we do not want to require the user to build an SQL query.

- Once the data is expressed as a time series, we want some control structures to compute with those time series.

- Want to be able to interface to the host generated language (python?) in order to use existing libraries and to easily program specialized functions.
Program Structure

```
script Foo() //should reside in file Foo.onc, should first letter be a cap
/**
Documentation comment. This comment should be returned by the command "help foo"
*/

// ------- USE CLAUSES ------------------------------

// ------- GROUP DEFINITIONS -----------------------

// ------- FILTERS ---------------------------------

// ------- COMPUTATIONS ----------------------------

{}
```

- Header, documentation and computation block required, others optional.
- Sections must come in this order.
script FilterTest()
/**
 * This file demos filters ...
*/
// The filter is applied over the whole database, resulting in the data
// which will be considered in the computations part

population is
  Id: 1000, 2000, 3000
  Sex: M
  Birthyear: 1967
  PostalCode: K2G6K8
  Diagnosis: breast

doctors are
  Id: 2123, 1231, 1415

period is
  Dates: 2013-01-01, 2015-01-01

events are
  Events: ct_sim_booked

{ foreach Patient p
  print p
}
Any order and repetition allowed?

- the four sections, population, doctors, period and events may come in any order, and may be omitted
- if a section is omitted, then the '*' value is implied for all the fields (i.e. no filtering)
- if a section is repeated, then any field that is redefined becomes the active filter.
- inside the population and period sections the fields can be listed in any order
- if a field is omitted, then the '*' value is implied for all those fields
- if a field is repeated, then the last definition is the one taken (should redefinition be a warning?)
What does a group file look like? - myGroups.grp

/**
 * This file defines a set of data that can easily be changed to
 * make it specific to particular queries or doctor’s interests.
 */

group Id myId = {1001, 2000}
group Id extraId = {400, 500}
group Id myPatientIds = {100, 200, 300, 500, <extraId>}
group Sex myGenders = {M, F}
group Birthyear myBirthyears = {1993, 2014, 1960}
group Diagnosis myDiagnosis = {breast, prostate, liver}
group Days myWorkDays = {Mon, Tues, Wed, Thurs, Fri}
group Years my_years = {2014, 2015, 2016}

Other types are: Postalcode, Date, Hour, Event
You can include some predefined groups, and also define some more

```plaintext
// --- uses
use myGroups.grp, ExtraGroups.grp

// ------- GROUP DEFINITIONS --------------------
// define a new group - string by default, other group names with <>
group Diagnosis diaglist = {breast, prostate}

// here is an example of using an existing group
group Diagnosis diaglist2 = {<diaglist>, liver}

// should you allow for some regular expressions for group values?
```
Database views to Event Streams

- The use, groups and filter sections set up all the information needed to determine what information needs to be extracted from the database.

- The compiler will generate SQL queries that will result in the information needed to generate an internal representation of an event stream, and it will create an efficient representation of the event trace.

- What is a reasonable representation? Want to not use excess space, but also want links for quickly traversing all events, all events for a patient, and perhaps other specializations.

- The computation section of the program computes over the event trace, and also assumes a table of patient info and doctor info for all patients and doctors that occur in the events.
**What are events?** Before treatment planning group:

```plaintext
consult_referral_received(time, patientid)
initial_consult_booked(time, patientid, doctorid) ... room?
initial_consult_completed(time, patientid, doctorid)
CT_sim_booked(time, patientid, doctorid) ... room?
ready_for_CT_sim(time, patientid, doctorid)
```

Treatment planning group:

```plaintext
CT_sim_completed(time, patientID, doctorID)
ready_for_initial_contour(time, patientID, doctorID) ... dosometristid?
ready_for_MD_contour(time, patientID, doctorID)
ready_for_dose_calculation(time, patientID, doctorID)
prescription_approved_by_MD(time, patientID, doctorID)
ready_for_physics_QA(time, patientID, doctorID) ... physicistid?
ready_for_treatment(time, patientID, doctorID)
machine_rooms_booked(time, patientID, doctorID) ... machines?
patient_contacted(time, patientID, doctorID)
```
vikramPatientData.grp

/**
 * Contains all the information I might want to use across OncoTime programs
 */

group  Id patientGroupOne = {1 to 250, 300 to 400, 1001}
group  Birthyear patientBirthyearRange = {1950 to 1970}
script DailyPatientHistory()

/**
  * Generates my patient Timelines.
  */

// ---- Change data in this group file ----
use vikramPatientData.grp

// ---- Filters ----
population is
  Id: <patientGroupOne>
  Birthyear: <patientBirthyearRange>
  Sex: M, F

// ---- Computations ----
{ foreach Patient p
    print p
}

Example 2 from Reference Compiler

script Barcharts()
/**
 * Generates barcharts.
 */

// ---- Change data in this group file ----
use vikramPatientData.grp

// ---- Filters ----
population is
    Id: <patientGroupOne>
    Birthyear: <patientBirthyearRange>
    Sex: M, F

{
    table t = count Patients by Birthyear
    table s = count Patients by Diagnosis
    table v = count Doctors by Id

    print t
    print s
    print v
}

Example 3 from Reference Compiler

script PatientDoctorDiagnosis()
/**
 * Prints all the informations for male patients who came in between
 * 2010 and 2015.
 * All months except for December.
 */

group Months myWorkMonths = {01, 02, 03 to 10}

population is
   Sex: M
   Id: 1 to 2500
   Birthyear: 1950 to 1970

period is
   Months: <myWorkMonths>, 11
   Years : 2010 to 2015

{ foreach Patient p
   { print p
      foreach Doctor d
      { print d
         foreach Diagnosis diag
         { print diag

   }
Example 4 from Reference Compiler

```plaintext
script PatientSequences()
/**
 * Generates my patient Timelines.
 */

// ---- Change data in this group file ----
use vikramPatientData.grp

// ---- Filters ----
population is
    Id: <patientGroupOne>
    Birthyear: <patientBirthyearRange>
    Sex: M, F

{ list s = sequences like
    [ct_sim_booked ->
        ct_sim_completed | patient_arrives ->
        end]

    foreach member i in s
        print i
}
```
Example 5 from Reference Compiler

```script
ParameterExpansion(Sex s, Birthyear b1, Birthyear b2, Events e)
/**
 * Parameter example.
 */

group Birthyear myBirthyears = {<b1>, 1993, 2012, <b2>}
population is
  Id: 13456, 134, 2455
  Sex: M, F
  Birthyear: <myBirthyears>
  Diagnosis: breast, prostate, <e> // can be strings or groups
  PostalCode: H4X
period is
  Months: 01, 02, 03
  Days: Mon, Tues, Wed, Thurs, Fri, Sat, Sun
events are
  Events: <e>

{ foreach Doctor d
  print d
}
```
Some possible computations - may not match reference compiler

```plaintext
foreach patient p
    print p

// optional where clause ??
foreach patient p // [where gender is female, postalcode is K]
    print timeline of p // all events, ordered by time, for a patient
    // can support a variety of nice visualizations

foreach diagnosis d // [where diagnosis is breast, prostate]
    { print d
        foreach patient p
            print ID, Gender, Age, Diagnosis of p // field names with caps
    }

foreach doctor d
    print timeline of d
```
Tables - basically association tables between keys and values

```plaintext
table x = count patients by Diagnosis // table of pairs (Diagnosis : n)
```

// What are good high-level operators to provide for tables?

```plaintext
foreach element i of x
    print x[i] // prints pairs

print x.length
```

// plot

```plaintext
barchart x // [to filename]?
```
Sequences - one of the key abstractions

// each p1 is either an identifier or a group

foreach sequence s like []
    // [patient_arrives -> patient_seen]
    // [patient_arrives(p) -> patient_seen(p)]
    // [e1 -> e2 | e3 -> e4]
    // [e1 -> {e2, e3} -> e4]
    // [e1 -> {e2, e3}* -> e4]
    // [e1 -(not e2)-> end]
    print s

// lists are lists of sequences
list S = sequences like []
foreach member s in S
    print s


Using the host language to compute

// call out to native code
table z = native(func,x,y)  // where x and y are tables, sequences, or
                          // lists of sequences
sequence z = native(func,x,y)
list l = native(func,x,y)

• Need to define an interface between your internal representation and the representation expected by
  the native call.

• Perhaps easier if you generate code in the same language as the native code (Python?)
What are the challenges?

- Write the grammar. Maybe leave quite a bit of checking to a weeding phase, which is aided by an external structure.

- Determine what static checks including type checks are required.

- Design the code generation for the MySQL queries.

- Design the events representation, and store results of queries in that representation.

- Generate the code generation for computation code as computations over the events.

- You can simplify the language if it gets too complex, and we can add new language features if things go easily. We will have a core set of features that you must implement.