On Turning Domain Knowledge into Tools

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Writing Software

vs.

Creating a Scientific Theory

Scientific Theories & Models

- A scientific theory is an explanation of an aspect of the natural world that can be repeatedly tested, in accordance with the scientific method, using a predefined protocol of observation and experiment
  - "The Structure of Scientific Theories" in The Stanford Encyclopedia of Philosophy
- The scientific method involves
  - the proposal and testing of hypotheses,
    - by deriving predictions from the hypotheses about the results of future experiments
  - then performing those experiments to see whether the predictions are valid
- A Model is an abstraction of an aspect of the world for a specific purpose. Therefore a Scientific Theory is a Model.
  - But a Model is not always a Scientific Theory

Creating a Scientific Theory is (evermore) Writing Software

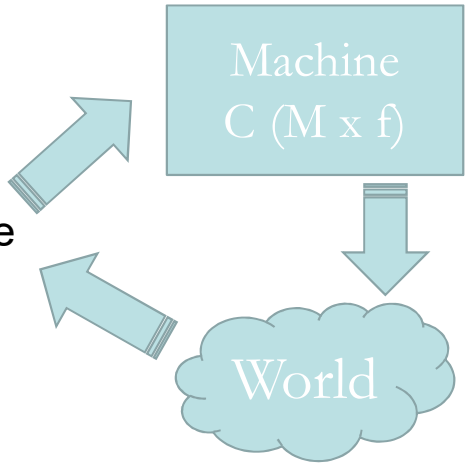
- Mathematics used to be the language of science...
  … when science was simple enough
  - Newton's gravity
    - 2 bodies problem has an analytical solution (Maths)
    - 3+ bodies problem?
  - Solution: model it into software and run it on a computer
    - aka Simulation
    - Idem for nuclear reactions, QCD, meteo, climate …
- Informatics is the language of science of the 21th
  - Of course Math still has a role to play

Conversely writing (usefull) Software is like Creating a Scientific Theory

- A Machine is made of
  - A computer C
  - Model M
  - Function f

} Software

- Does it do what I want?
  - Test it w.r.t. the World!

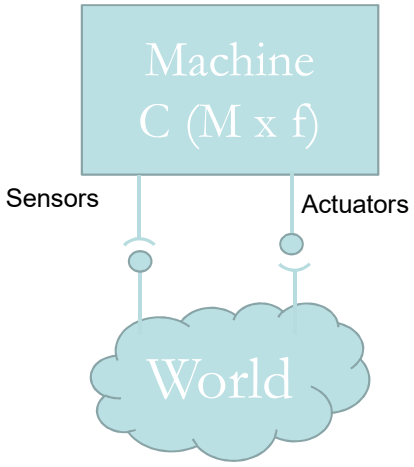


The World and the Machine [Jackson]

- A Machine is made of
  - A computer C
  - Model M
  - Function f

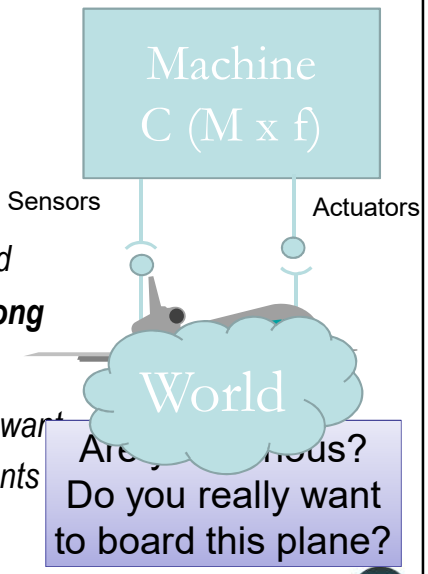
} Software

- Typical evolution
  1. Model the world
  2. Monitor the world
  3. Control the world
  4. Sometimes *becomes* the world (but that's not the point of this talk)
     - Bank accounts, Expedia…



Caveat

- A Machine is made of
  - A computer C
    - *Nobody knows any longer how modern processors work*
  - Model M
    - *Abstraction of an aspect of the world*
    - *it is incomplete, partial and thus **wrong***
  - Function f
    - *Users do not really know what they wan*
    - *Many bugs traced to bad requirements*



Solution: Abstraction + Separation of Concerns

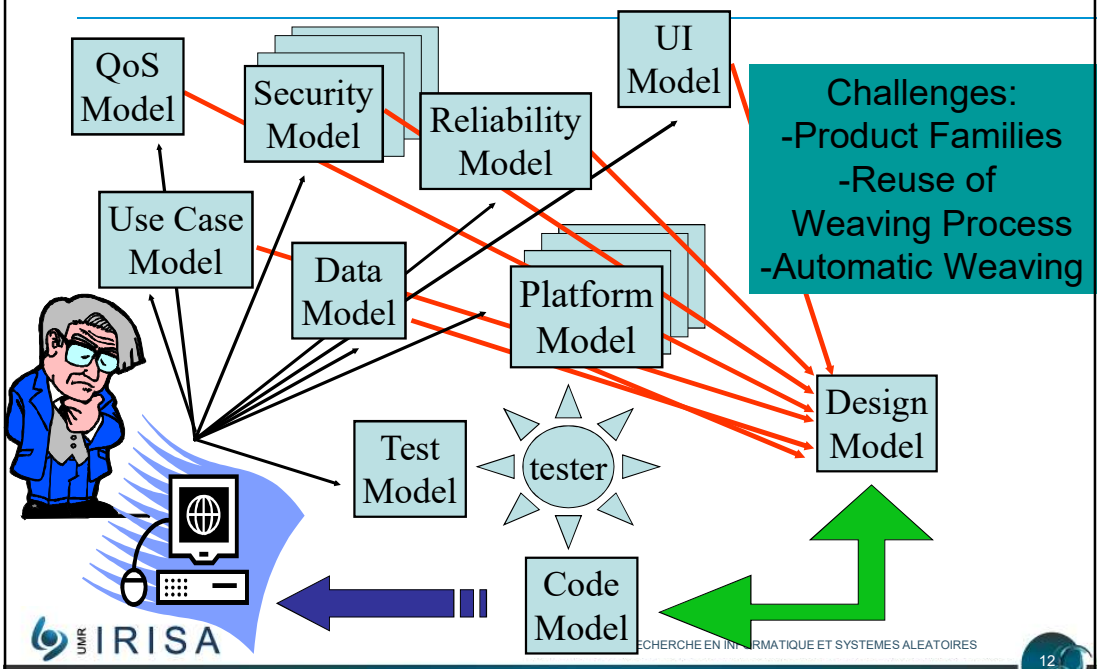
- Of course [Dijkstra]!
  - Abstraction on hardware
  - Models are SoC + abstraction of the world
  - Funtions must be understood => abstracted
- Are all these abstractions consistent?
  - Do the thing right [Brooks]: applied maths, eg. Proofs
- Are they close enough to reality for the purpose?
  - Do the right thing [Brooks]: Test!

Evolution towards better abstractions

- The historical approach (50's->80's)
  - Machine = C (M x f) : M x f is « compiled »
    - Typical in Fortran, C, control automation, …
    - Most efficient, but no SoC thus brittle wrt f->f'
- The object oriented revolution (70's -> 2000's)
  - Machine = C(M) x C(f) : M x f is « interpreted » (M still there)
    - Then it makes it easy to have Machine' = C(M) x C(f')
  - Still hard to keep model separated from technical concerns
    - persistency, security, FT, speed…
- One DSL (Domain Specific Language) per concern (90's -> ?)
  - Machine = C(M1) x C(M2) x C(M3) x C(f1) x C(f2) …

Writing software
is (will be)
composing abstractions
described in different languages

Modeling and Weaving



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Complex Software Intensive Systems

- Multiple viewpoints & stakeholders
- Multiple concerns (technicals…)
- Multiple domains of expertise
- => Need languages to express them!
  - In a meaningful way for experts
  - With tool support (analysis, code gen., V&V..)
    - Which is still costly to build
  - At some point, all these concerns must be ***integrated***

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Example: jHipster

- JHipster is a development platform to generate, develop and deploy Spring Boot + Angular Web applications and Spring microservices.
- **Goal** is to generate a complete and modern Web app or microservice architecture, unifying:
  - A high-performance and robust Java stack on the server side with Spring Boot
  - A sleek, modern, mobile-first front-end with Angular and Bootstrap
  - A robust microservice architecture with JHipster Registry, Netflix OSS, ELK stack and Docker
  - A powerful workflow to build your application with Yeoman, Webpack/Gulp and Maven/Gradle
- **Use of 40+ different DSLs!**

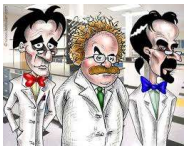
Limits of General Purpose Languages (1)

- **Abstractions** and **notations** used are not natural/suitable for the stakeholders
  - Even with the best languages, impossible to keep all concerns separated down to the implementation


```
if (newGame) resources.free();
s = FILENAME + 3;
setLocation(); load(s);
loadDialog.process();

try { setGamerColor(RED); }
catch(Exception e) { reset(); }
while (notReady) { objects.make();
if (resourceNotFound) break; }

byte result; // сменить на int!
music();
System.out.print("");
```



Limits of General Purpose Languages (2)

- Not targeted to a **particular** kind of problem, but to any kinds of software problem.

GLP

DSLs

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General-Purpose Languages

« Another lesson we should have learned from the recent past is that the development of 'richer' or 'more powerful' programming languages was a mistake in the sense that these baroque monstrosities, these conglomerations of idiosyncrasies, are really unmanageable, both mechanically and mentally.

I see a great future for very systematic and very modest programming languages »

1972 ACM Turing Lecture, « The Humble Programmer » Edsger W. Dijkstra

aka **Domain-Specific Languages**

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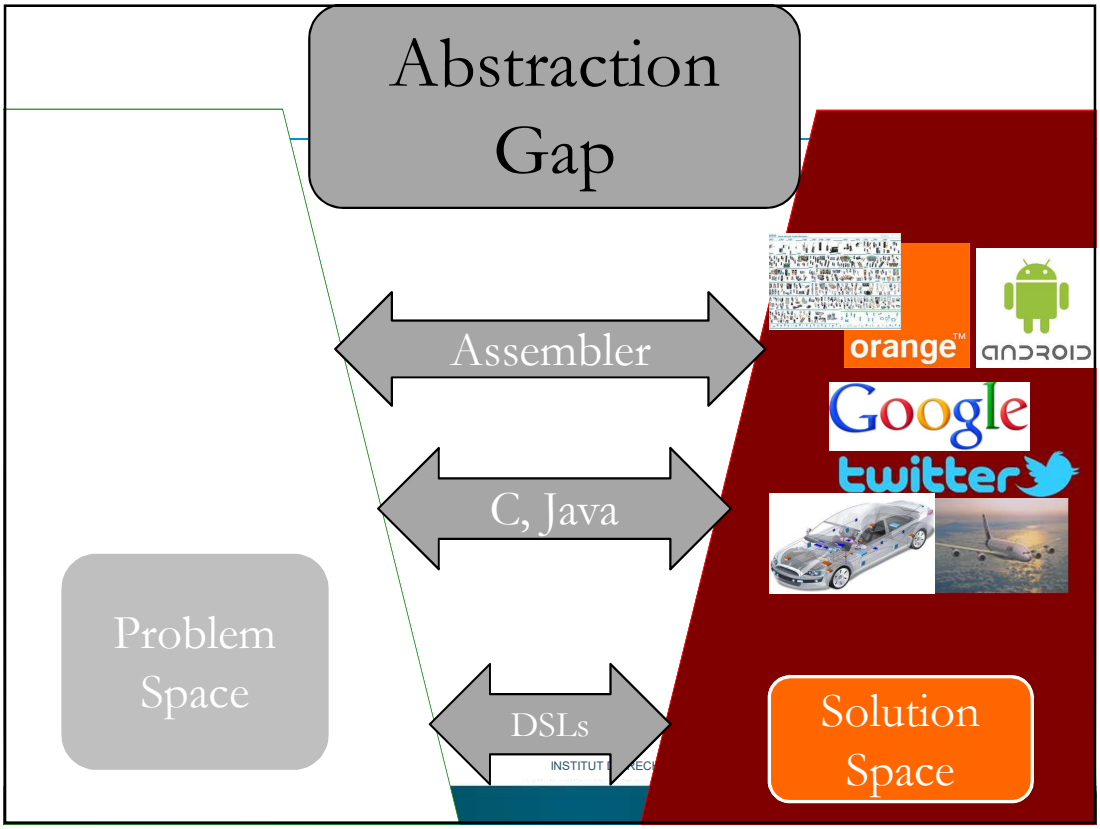
Domain Specific Languages

- Targeted to a **particular** kind of problem
  - with dedicated notations (textual or graphical), support (editor, checkers, etc.)
- Promises: more « efficient » languages for resolving a set of specific problems in a domain
- Each concern described in its own language => reduce abstraction gap



Domain Specific Languages (DSLs)

- Long history: used for almost as long as computing has been done.
- You're using DSLs in a daily basis
  - Even if you do not recognize them as DSLs (yet), because they have many different forms [Fowler]
- **More and more people are building DSLs**
  - **How can we help them?**

HTML

```
<?xml version="1.0" encoding="iso-8859-1"?>
<!DOCTYPE html PUBLIC "-//W3C//DTD XHTML 1.0 Transitional//EN" "DTD/xhtml1-transitional.dtd">
<html xml:lang="en" lang="en" xmlns="http://www.w3.org/1999/xhtml">
  <head>
      <title>Hello World</title>
  </head>
  <body>
      <p>My first Web page.</p>
  </body>
</html>
```

Domain: web (markup)

CSS

```
.CodeMirror {
  line-height: 1;
  position: relative;
  overflow: hidden;
}

.CodeMirror-scroll {
  /* 30px is the magic margin used to hide the element's real scrollbars */
  /* See overflow: hidden in .CodeMirror, and the paddings in .CodeMirror-sizer */
  margin-bottom: -30px; margin-right: -30px;
  padding-bottom: 30px; padding-right: 30px;
  height: 100%;
  outline: none; /* Prevent dragging from highlighting the element */
  position: relative;
}
.CodeMirror-sizer {
  position: relative;
}
```

Domain: web (styling)

Makefile

```
PACKAGE      = package
VERSION      = `date "+%Y.%m%d%"`
RELEASE_DIR  = ..
RELEASE_FILE = $(PACKAGE)-$(VERSION)

# Notice that the variable LOGNAME comes from the environment in
# POSIX shells.
#
# target: all - Default target. Does nothing.
all:
        echo "Hello $(LOGNAME), nothing to do by default"
        # sometimes: echo "Hello ${LOGNAME}, nothing to do by default"
        echo "Try 'make help'"

# target: help - Display callable targets.
help:
        egrep "^# target:" [Mm]akefile

# target: list - List source files
list:
        # Won't work. Each command is in separate shell
        cd src
        ls

        # Correct, continuation of the same shell
        cd src; \
        ls
```

Domain: software building

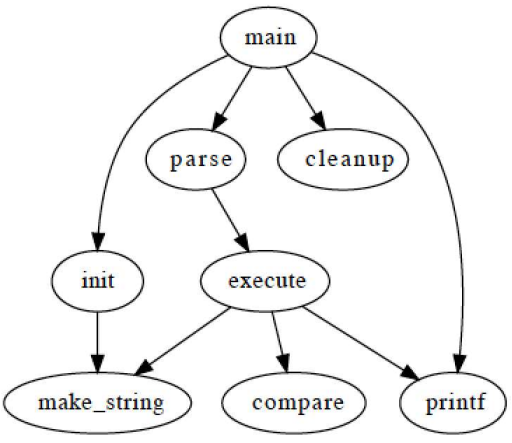
Regular expression

```
<TAG\b[^>]*>(.*?)</TAG>
```

Domain: strings (pattern matching)

Graphviz

```
digraph G {
main -> parse -> execute;
main -> init;
main -> cleanup;
execute -> make_string;
execute -> printf
init -> make_string;
main -> printf;
execute -> compare;
 }
```

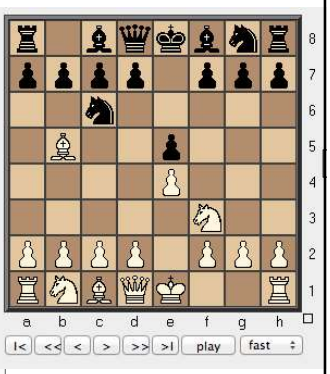


Domain: graph (drawing)

PGN (Portable Game Notation)

```
[Event "F/S Return Match"]
[Site "Belgrade, Serbia Yugoslavia|JUG"]
[Date "1992.11.04"]
[Round "29"]
[White "Fischer, Robert J."]
[Black "Spassky, Boris V."]
[Result "1/2-1/2"]

1. e4 e5 2. Nf3 Nc6 3. Bb5 {This opening is called the Ruy Lopez.} 3... a6
4. Ba4 Nf6 5. O-O Be7 6. Re1 b5 7. Bb3 d6 8. c3 O-O 9. h3 Nb8  10. d4 Nbd7
11. c4 c6 12. cxb5 axb5 13. Nc3 Bb7 14. Bg5 b4 15. Nb1 h6 16. Bh4 c5 17. dxe5
Nxe4 18. Bxe7 Qxe7 19. exd6 Qf6 20. Nbd2 Nxd6 21. Nc4 Nxc4 22. Bxc4 Nb6
23. Ne5 Rae8 24. Bxf7+ Rxf7 25. Nxf7 Rxe1+ 26. Qxe1 Kxf7 27. Qe3 Qg5 28. Qxg5
hxg5 29. b3 Ke6 30. a3 Kd6 31. axb4 cxb4 32. Ra5 Nd5 33. f3 Bc8 34. Kf2 Bf5
35. Ra7 g6 36. Ra6+ Kc5 37. Ke1 Nf4 38. g3 Nxh3 39. Kd2 Kb5 40. Rd6 Kc5 41. Ra6
Nf2 42. g4 Bd3 43. Re6 1/2-1/2
```



Domain: chess (games)

R: a DSL for statisticians

- a dynamic, lazy, functional, object-oriented programming language
  - with a rather unusual combination of features
- designed to
  - ease learning by non-programmers
  - enable rapid development of new statistical methods.
- base is estimated to be as high as 2 million users.

SQL

```
SELECT Book.title AS Title,
       COUNT(*) AS Authors
FROM   Book
JOIN   Book_author
  ON   Book.isbn = Book_author.isbn
GROUP BY Book.title;

INSERT INTO example
(field1, field2, field3)
VALUES
('test', 'N', NULL);
```

Domain: database (query)

There are more DSLs than you think…

… because DSLs exist with different *shapes*

Different shapes for a DSL: External

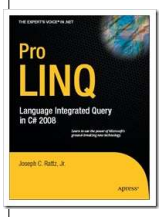
- External DSLs with their own syntax and domain-specific tooling
  - Nice for the non-programmers
  - Good for separation of concerns
  - Bad for integration
- Example: SQL

```
-- Select all books by authors born after 1920,
-- named "Paulo" from a catalogue:
SELECT *
  FROM t_author a
  JOIN t_book b ON a.id = b.author_id
 WHERE a.year_of_birth > 1920
   AND a.first_name = 'Paulo'
 ORDER BY b.title
```


Different shapes for a DSL: Internal/Embedded

- Internal/Embedded DSLs, blending their syntax and semantics into host language (C++, Scala, C#)
  - Splendid for the gurus
  - Hard for the rest of us
  - Excellent integration
- Example: SQL in LINQ/C#

```
// DataContext takes a connection string
DataContext db = new   DataContext("c:\\northwind\\northwnd.mdf");
// Get a typed table to run queries
Table<Customer> Customers = db.GetTable<Customer>();
// Query for customers from London
var q =
   from c in Customers
   where c.City == "London"
   select c;
foreach (var cust in q)
   Console.WriteLine("id = {0}, City = {1}", cust.CustomerID, cust.City);
```



Different shapes for a DSL: Implicit [Fowler]

- Implicit = from plain-old API to more fluent APIs
  - Good for Joe the Programmer
  - Bad for separation of concerns, V&V
  - Good for integration
- Example: SQL

```
Connection con = null;

// create sql insert query
String query = "insert into user values(" + student.getId() + ",'"
  + student.getFirstName() + "','" + student.getLastName()
  + "','" + student.getEmail() + "','" + student.getPhone()
  + "')";
try {
 // get connection to db
 con = new CreateConnection().getConnection("che
   "root");

 // get a statement to execute query
 stmt = con.createStatement();

 // executed insert query
 stmt.execute(query);
 System.out.println("Data inserted in table !");
```

```
Result<Record> result =
create.select()
      .from(T_AUTHOR.as("a"))
      .join(T_BOOK.as("b")).on(a.ID.equal(b.AUTHOR_ID))
      .where(a.YEAR_OF_BIRTH.greaterThan(1920)
      .and(a.FIRST_NAME.equal("Paulo")))
      .orderBy(b.TITLE)
      .fetch();
```


C: a DSL for System Programming?

- Hum, wait a minute, is not C a GPL?
  - Yes, but where it is really good is when you write low level stuff
- But what is the difference between a GPL and a DSL then?
  - Turing incompletness not considered anymore as a criteria
  - Not always black & white, large greyscale

Where does Software go with DSL?

- A DSL program is a 3D abstraction
  - from the domain (cf Newton vs Relativity),
  - from the function (requirements)
  - from the platform
- Embrace uncertainty
  - Smaller abstractions than with GPL
    - We better know and control the unknown
  - Apply rigorous methods to uncertain systems so that we get known uncertainties

DSLs for the masses:

Helping people turn domain knowledge into tools



Issues of DSL Engineering
DSL is Software!

- Versions
- Variants
- Separation of concerns / Composition

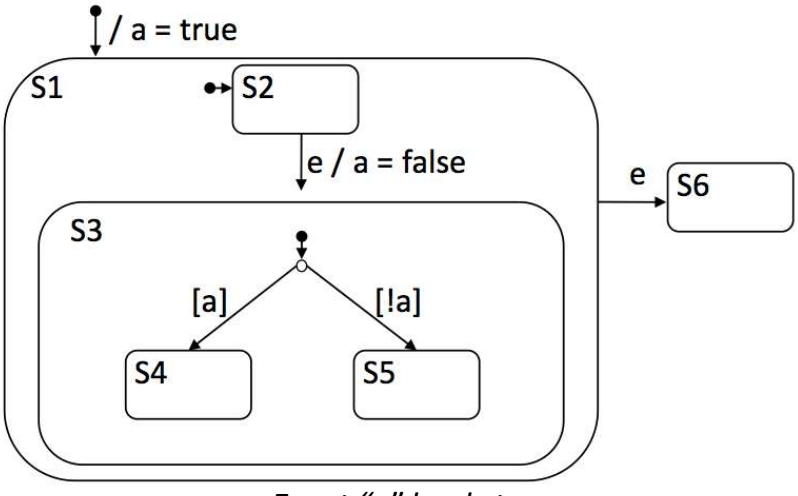
Versions of a DSL: a Typical Lifecycle

- Starts as a simple 'configuration' mecanism
  - for a complex framework, e.g.; video processing
- Grows more and more complex over time
  - ffmpeg -i input.avi -b:v 64k -bufsize 64k output.avi
    - Cf https://www.ffmpeg.org/ffmpeg.html
- Evolves into a more complex language
  - ffmpeg config file
    - A preset file contains a sequence of option=value pairs, one for each line, specifying a sequence of options. Lines starting with the hash (#) character are ignored and are used to provide comments.
- Add macros, if, loops,…
  - might end up into a Turing-complete language!

Variants of a DSL

- Abstract syntax variability
  - functional variability
    - E.g. Support for super states in StateCharts
      - 50+ variants of StateCharts Syntax have been reported!
- Concrete syntax variability
  - representation variability
    - E.g. Textual/Graphical/Color…
- Semantics variability
  - interpretation variability
    - E.g. Inner vs outer transition priority

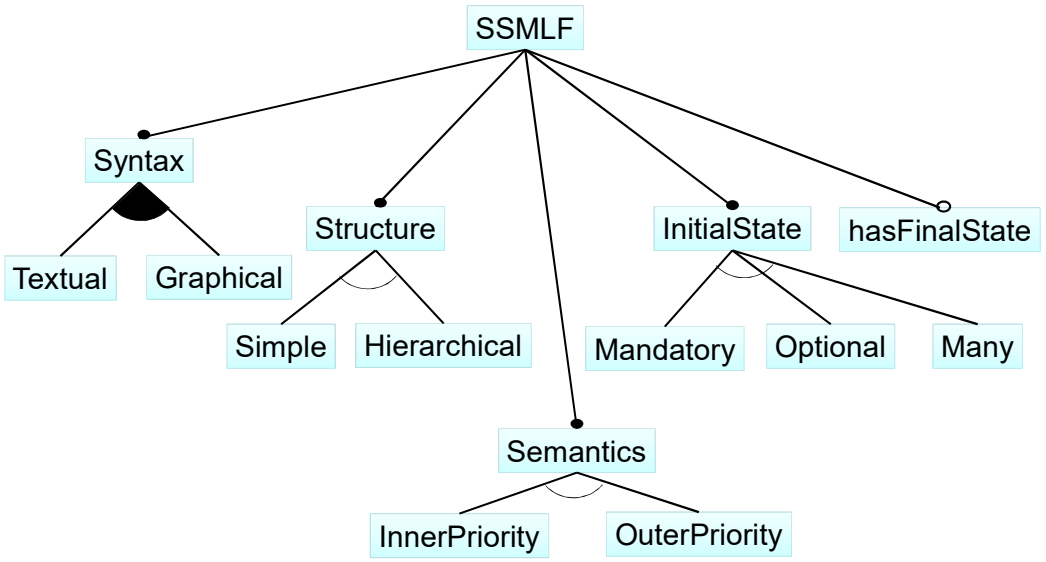
Variants Also at Semantic Level



Event "e" leads to
S4 (UML), S5 (Rhapsody), or (S6) Stateflow

"UML vs. Classical vs. Rhapsody Statecharts: Not All Models are Created Equal ", Michelle Crane, Juergen Dingel

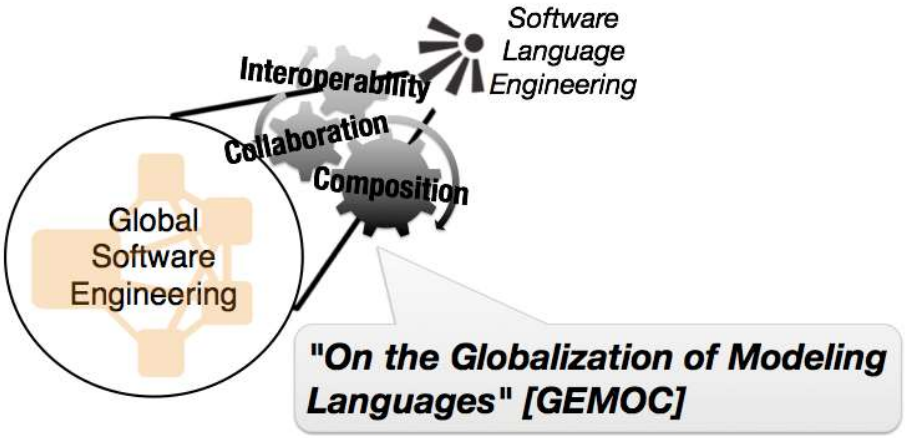
A (Simplified) State Machine Language Family



Gemoc Initiative

➠Visit http://gemoc.org

Focuses on **SLE tools and methods for interoperable, collaborative, and composable modeling languages**



DSL: From Craft to **Engineering**

- From supporting a single DSL…
  - Concrete syntax, abstract syntax, semantics, pragmatics
    - Editors, Parsers, Simulators, Compilers…
    - But also: Checkers, Refactoring tools, Converters…
- …To supporting Multiple DSLs
  - Interacting altogether
  - Each DSL with several flavors(variants)
  - And evolving over time (versions)
- Product Lines of DSLs!
  - Safe reuse of the tool chains?
  - Backward compatibility, Migration of artifacts?

Our Goal

- Ease the definition of tool-supported DSL families
  - How to ease and validate the definition of new DSLs/tools?
  - How to correctly reuse existing tools?

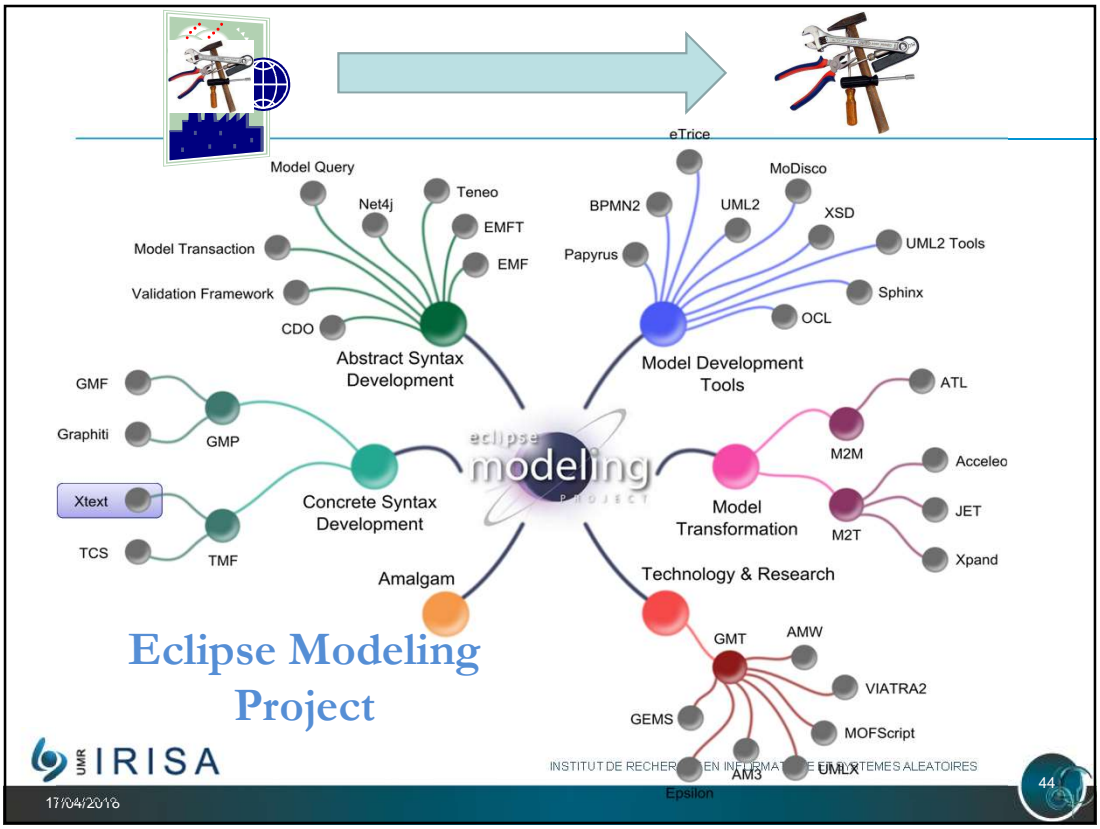
⇒ Bring external DSL design abilities to the masses

⇒Use abstractions that are familiar to the OO Programmer to define languages

⇒ set of DSL to build DSLs

⇒ Leverage static typing to foster safe reuse

⇒With a appropriate definition of type



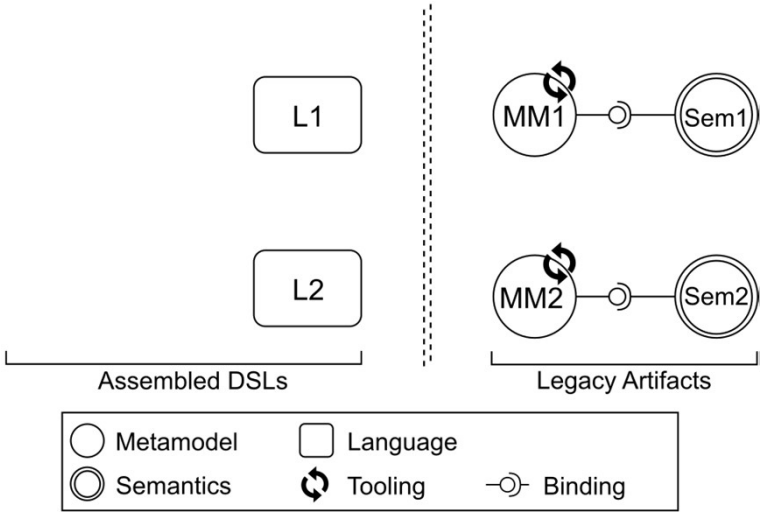
Tools built with MDE

- A tool (aka Model Transformation) is just a program working with specific OO data structures (aka meta-models) representing abstract syntax ~~trees~~ (graphes).
  - Kermeta approach: organize the program along the OO structure of the meta-model
  - Any software engineer can now build a DSL toolset!
    - No longer just for genius…
- Product Lines of DSLs = SPL of OO programs
  - Safe reuse of the tool chains -> Static typing
  - Backward compatibility, Migration of artifacts -> Adaption

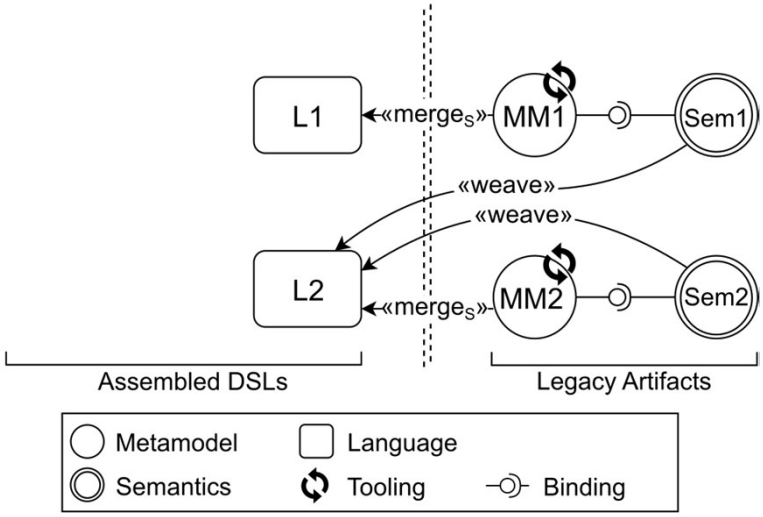
Melange: a Meta-language for Modular and Reusable Development of DSLs

with Thomas Degueule, Benoit Combemale, Arnaud Blouin, Olivier Barais

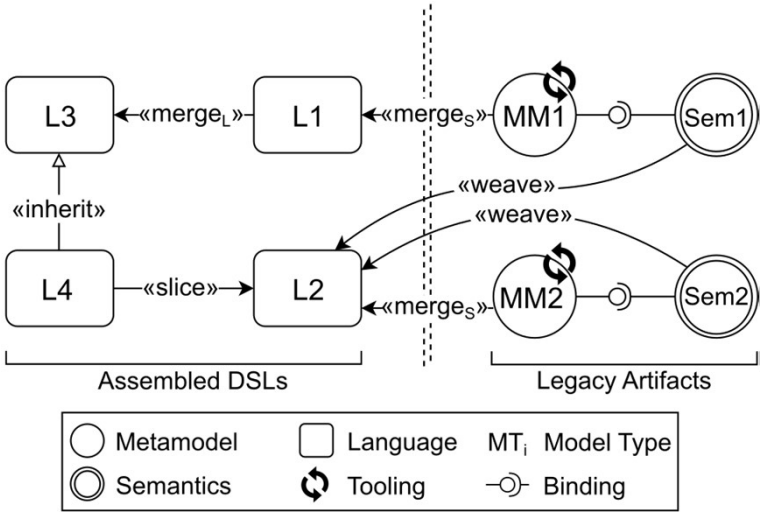
Approach Overview



Approach Overview

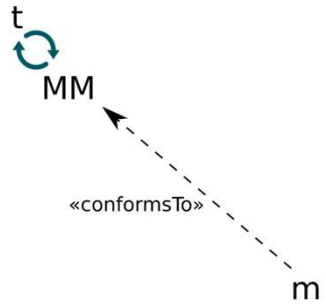


Approach Overview

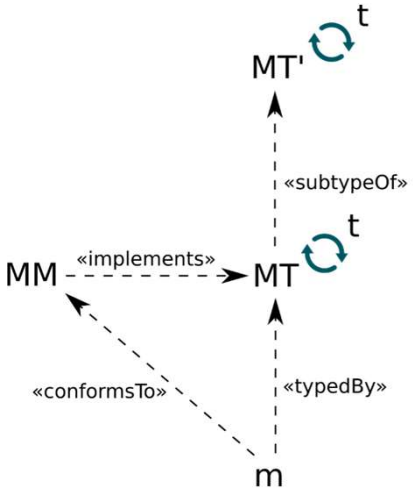


Inspired by *eg*. Erdweg *et al.*, *Language Composition Untangled*, LDTA, 2012

TOOL REUSE THROUGH MODEL TYPING



TOOL REUSE THROUGH MODEL TYPING



Steel *et al.*, *On Model Typing*, SoSyM, 2007
Guy *et al.*, *On Model Subtyping*, ECMFA, 2012

LANGUAGE DEFINITION

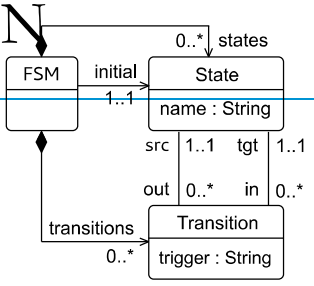
$$\mathcal{L} \triangleq \langle AS, Sem, MT \rangle$$

$$Sem(\mathcal{L}) \triangleq (A_i^t \in Aspects) \text{ where}$$
$$\forall A_i^t \in Sem(\mathcal{L}), \exists c \in AS(\mathcal{L}) : c \text{ match } t$$
$$\forall A_i^t, A_j^t \in Sem(\mathcal{L}) : A_i^t \lhd A_j^t \implies i > j$$
$$Sem \bullet Sem' \equiv Sem \frown Sem'$$
$$sig(Sem) \triangleq \mathop{\circ\!\!\bigcup}_{A_i^t \in Sem} sig(A_i^t)$$
$$MT(\mathcal{L}) \triangleq AS(\mathcal{L}) \circ sig(Sem(\mathcal{L}))$$
$$\mathcal{L} \xleftarrow{m} AS' = \langle AS \circ AS', Sem, MT \circ AS' \rangle$$
$$\mathcal{L} \xleftarrow{w} Sem' = \langle AS, Sem \bullet Sem', MT \circ sig(Sem') \rangle$$
$$\mathcal{L} \uplus \mathcal{L}' = \langle AS \circ AS', Sem \bullet Sem', MT \circ MT' \rangle$$
$$\mathcal{L} \oplus \mathcal{L}' = \langle AS \circ AS', Sem' \bullet Sem, MT'' \rangle \text{ where}$$
$$MT'' = MT \circ MT' \text{ and}$$
$$MT'' <: MT'$$
$$\Lambda_-^+(\mathcal{L}_1, c) = \langle AS_2, Sem_2, MT_2 \rangle, \text{ where:}$$
$$AS_2 \triangleq \lambda_-^+(AS_1, c),\ AS_2 \subseteq AS_1,$$
$$Sem_2 \triangleq \{A_i^t \in Sem_1, fp(A_i^t, AS_1) \subseteq AS_2\},$$
$$MT_1 <: MT_2,$$

LANGUAGE DEFINITION

$$\mathcal{L} \triangleq \langle AS, Sem, MT \rangle$$

$$Sem(\mathcal{L}) \triangleq (A_i^t \in Aspects) \text{ where}$$
$$\forall A_i^t \in Sem(\mathcal{L}), \exists c \in AS(\mathcal{L}) : c \text{ match } t$$
$$\forall A_i^t, A_j^t \in Sem(\mathcal{L}) : A_i^t \lhd A_j^t \implies i > j$$
$$Sem \bullet Sem' \equiv Sem \frown Sem'$$
$$sig(Sem) \triangleq \mathop{\circ\!\!\bigcup}_{A_i^t \in Sem} sig(A_i^t)$$
$$MT(\mathcal{L}) \triangleq AS(\mathcal{L}) \circ sig(Sem(\mathcal{L}))$$
$$\mathcal{L} \xleftarrow{m} AS' = \langle AS \circ AS', Sem, MT \circ AS' \rangle$$
$$\mathcal{L} \xleftarrow{w} Sem' = \langle AS, Sem \bullet Sem', MT \circ sig(Sem') \rangle$$
$$\mathcal{L} \uplus \mathcal{L}' = \langle AS \circ AS', Sem \bullet Sem', MT \circ MT' \rangle$$
$$\mathcal{L} \oplus \mathcal{L}' = \langle AS \circ AS', Sem' \bullet Sem, MT'' \rangle \text{ where}$$
$$MT'' = MT \circ MT' \text{ and}$$
$$MT'' <: MT'$$
$$\Lambda_-^+(\mathcal{L}_1, c) = \langle AS_2, Sem_2, MT_2 \rangle, \text{ where:}$$
$$AS_2 \triangleq \lambda_-^+(AS_1, c),\ AS_2 \subseteq AS_1,$$
$$Sem_2 \triangleq \{A_i^t \in Sem_1, fp(A_i^t, AS_1) \subseteq AS_2\},$$
$$MT_1 <: MT_2,$$



→

```
language Fsm {
syntax 'FSM.ecore'


}
```

LANGUAGE DEFINITION

$$\mathcal{L} \triangleq \langle AS, Sem, MT \rangle$$

$$Sem(\mathcal{L}) \triangleq (A_i^t \in Aspects) \text{ where}$$
$$\forall A_i^t \in Sem(\mathcal{L}), \exists c \in AS(\mathcal{L}) : c \text{ match } t$$
$$\forall A_i^t, A_j^t \in Sem(\mathcal{L}) : A_i^t \lhd A_j^t \implies i > j$$

$$Sem \bullet Sem' \equiv Sem \frown Sem'$$

$$sig(Sem) \triangleq \mathop{\overset{\circ}{\bigcup}}_{A_i^t \in Sem} sig(A_i^t)$$

$$MT(\mathcal{L}) \triangleq AS(\mathcal{L}) \circ sig(Sem(\mathcal{L}))$$

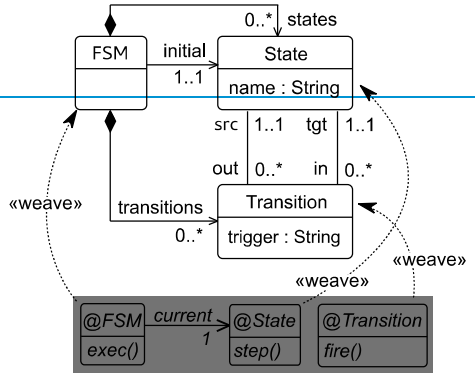
$$\mathcal{L} \xleftarrow{m} AS' = \langle AS \circ AS', Sem, MT \circ AS' \rangle$$

$$\mathcal{L} \xleftarrow{w} Sem' = \langle AS, Sem \bullet Sem', MT \circ sig(Sem') \rangle$$

$$\mathcal{L} \uplus \mathcal{L}' = \langle AS \circ AS', Sem \bullet Sem', MT \circ MT' \rangle$$

$$\mathcal{L} \oplus \mathcal{L}' = \langle AS \circ AS', Sem' \bullet Sem, MT'' \rangle \text{ where}$$
$$MT'' = MT \circ MT' \text{ and}$$
$$MT'' <: MT'$$

$$\Lambda_{-}^{+}(\mathcal{L}_1, c) = \langle AS_2, Sem_2, MT_2 \rangle, \text{ where:}$$
$$AS_2 \triangleq \lambda_{-}^{+}(AS_1, c),\ AS_2 \subseteq AS_1,$$
$$Sem_2 \triangleq \{A_i^t \in Sem_1, fp(A_i^t, AS_1) \subseteq AS_2\},$$
$$MT_1 <: MT_2,$$




```
language Fsm {
    syntax 'FSM.ecore'
    with ExecutableFsm
    with ExecutableState
    with ExecutableTransition

}
```


LANGUAGE DEFINITION

$$\mathcal{L} \triangleq \langle AS, Sem, MT \rangle$$

$$Sem(\mathcal{L}) \triangleq (A_i^t \in Aspects) \text{ where}$$
$$\forall A_i^t \in Sem(\mathcal{L}), \exists c \in AS(\mathcal{L}) : c \text{ match } t$$
$$\forall A_i^t, A_j^t \in Sem(\mathcal{L}) : A_i^t \lhd A_j^t \implies i > j$$

$$Sem \bullet Sem' \equiv Sem \frown Sem'$$

$$sig(Sem) \triangleq \mathop{\overset{\circ}{\bigcup}}_{A_i^t \in Sem} sig(A_i^t)$$

$$MT(\mathcal{L}) \triangleq AS(\mathcal{L}) \circ sig(Sem(\mathcal{L}))$$

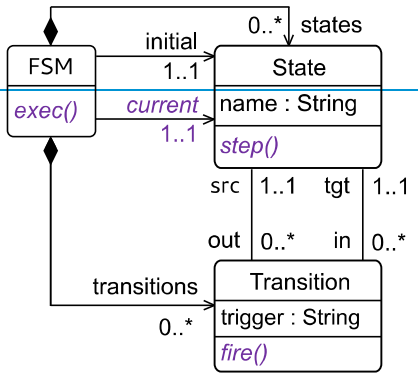
$$\mathcal{L} \xleftarrow{m} AS' = \langle AS \circ AS', Sem, MT \circ AS' \rangle$$

$$\mathcal{L} \xleftarrow{w} Sem' = \langle AS, Sem \bullet Sem', MT \circ sig(Sem') \rangle$$

$$\mathcal{L} \uplus \mathcal{L}' = \langle AS \circ AS', Sem \bullet Sem', MT \circ MT' \rangle$$

$$\mathcal{L} \oplus \mathcal{L}' = \langle AS \circ AS', Sem' \bullet Sem, MT'' \rangle \text{ where}$$
$$MT'' = MT \circ MT' \text{ and}$$
$$MT'' <: MT'$$

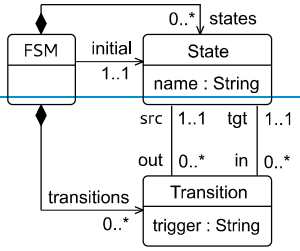
$$\Lambda_{-}^{+}(\mathcal{L}_1, c) = \langle AS_2, Sem_2, MT_2 \rangle, \text{ where:}$$
$$AS_2 \triangleq \lambda_{-}^{+}(AS_1, c),\ AS_2 \subseteq AS_1,$$
$$Sem_2 \triangleq \{A_i^t \in Sem_1, fp(A_i^t, AS_1) \subseteq AS_2\},$$
$$MT_1 <: MT_2,$$




```
language Fsm {
    syntax 'FSM.ecore'
    with ExecutableFsm
    with ExecutableState
    with ExecutableTransition
    exactType FsmMT
}
```

SYNTAX MERGING

$$\mathcal{L} \triangleq \langle AS, Sem, MT \rangle$$
$$Sem(\mathcal{L}) \triangleq (A_i^t \in Aspects) \text{ where}$$
$$\forall A_i^t \in Sem(\mathcal{L}), \exists c \in AS(\mathcal{L}) : c \text{ match } t$$
$$\forall A_i^t, A_j^t \in Sem(\mathcal{L}) : A_i^t \lhd A_j^t \implies i > j$$
$$Sem \bullet Sem' \equiv Sem \frown Sem'$$
$$sig(Sem) \triangleq \mathop{\mathring{\bigcup}}_{A_i^t \in Sem} sig(A_i^t)$$
$$MT(\mathcal{L}) \triangleq AS(\mathcal{L}) \circ sig(Sem(\mathcal{L}))$$
$$\mathcal{L} \xleftarrow{m} AS' = \langle AS \circ AS', Sem, MT \circ AS' \rangle$$
$$\mathcal{L} \xleftarrow{w} Sem' = \langle AS, Sem \bullet Sem', MT \circ sig(Sem') \rangle$$
$$\mathcal{L} \uplus \mathcal{L}' = \langle AS \circ AS', Sem \bullet Sem', MT \circ MT' \rangle$$
$$\mathcal{L} \oplus \mathcal{L}' = \langle AS \circ AS', Sem' \bullet Sem, MT'' \rangle \text{ where}$$
$$MT'' = MT \circ MT' \text{ and}$$
$$MT'' <: MT'$$
$$\Lambda_-^+(\mathcal{L}_1, c) = \langle AS_2, Sem_2, MT_2 \rangle, \text{ where:}$$
$$AS_2 \triangleq \lambda_-^+(AS_1, c),\ AS_2 \subseteq AS_1,$$
$$Sem_2 \triangleq \{A_i^t \in Sem_1, fp(A_i^t, AS_1) \subseteq AS_2\},$$
$$MT_1 <: MT_2,$$




```
language GuardedFsm {
    syntax 'FSM.ecore'

    with ExecutableFsm
    with ExecutableState
    with ExecutableTransition


    exactType GuardedFsmMT
}
```

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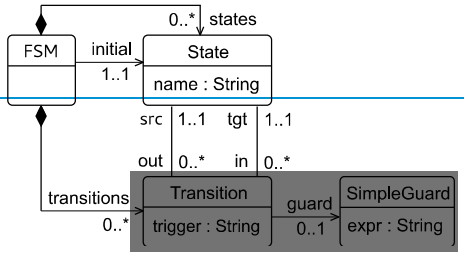
SYNTAX MERGING

$$\mathcal{L} \triangleq \langle AS, Sem, MT \rangle$$
$$Sem(\mathcal{L}) \triangleq (A_i^t \in Aspects) \text{ where}$$
$$\forall A_i^t \in Sem(\mathcal{L}), \exists c \in AS(\mathcal{L}) : c \text{ match } t$$
$$\forall A_i^t, A_j^t \in Sem(\mathcal{L}) : A_i^t \lhd A_j^t \implies i > j$$
$$Sem \bullet Sem' \equiv Sem \frown Sem'$$
$$sig(Sem) \triangleq \mathop{\mathring{\bigcup}}_{A_i^t \in Sem} sig(A_i^t)$$
$$MT(\mathcal{L}) \triangleq AS(\mathcal{L}) \circ sig(Sem(\mathcal{L}))$$
$$\mathcal{L} \xleftarrow{m} AS' = \langle AS \circ AS', Sem, MT \circ AS' \rangle$$
$$\mathcal{L} \xleftarrow{w} Sem' = \langle AS, Sem \bullet Sem', MT \circ sig(Sem') \rangle$$
$$\mathcal{L} \uplus \mathcal{L}' = \langle AS \circ AS', Sem \bullet Sem', MT \circ MT' \rangle$$
$$\mathcal{L} \oplus \mathcal{L}' = \langle AS \circ AS', Sem' \bullet Sem, MT'' \rangle \text{ where}$$
$$MT'' = MT \circ MT' \text{ and}$$
$$MT'' <: MT'$$
$$\Lambda_-^+(\mathcal{L}_1, c) = \langle AS_2, Sem_2, MT_2 \rangle, \text{ where:}$$
$$AS_2 \triangleq \lambda_-^+(AS_1, c),\ AS_2 \subseteq AS_1,$$
$$Sem_2 \triangleq \{A_i^t \in Sem_1, fp(A_i^t, AS_1) \subseteq AS_2\},$$
$$MT_1 <: MT_2,$$




```
language GuardedFsm {
    syntax 'FSM.ecore'
    syntax 'Guard.ecore'
    with ExecutableFsm
    with ExecutableState
    with ExecutableTransition


    exactType GuardedFsmMT
}
```

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SEMANTICS WEAVING

$$\mathcal{L} \triangleq \langle AS, Sem, MT \rangle$$

$$Sem(\mathcal{L}) \triangleq (A_i^t \in Aspects) \text{ where}$$
$$\forall A_i^t \in Sem(\mathcal{L}), \exists c \in AS(\mathcal{L}) : c \text{ match } t$$
$$\forall A_i^t, A_j^t \in Sem(\mathcal{L}) : A_i^t \lhd A_j^t \implies i > j$$

$$Sem \bullet Sem' \equiv Sem \frown Sem'$$

$$sig(Sem) \triangleq \mathop{\mathring{\bigcup}}_{A_i^t \in Sem} sig(A_i^t)$$

$$MT(\mathcal{L}) \triangleq AS(\mathcal{L}) \circ sig(Sem(\mathcal{L}))$$

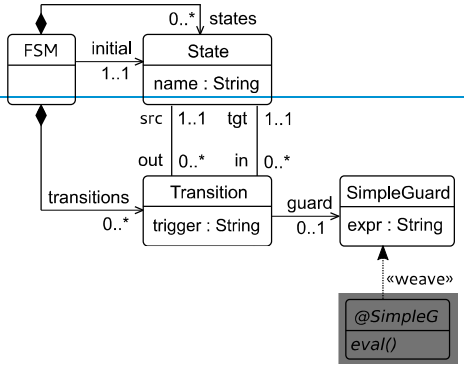
$$\mathcal{L} \xleftarrow{m} AS' = \langle AS \circ AS', Sem, MT \circ AS' \rangle$$

$$\mathcal{L} \xleftarrow{w} Sem' = \langle AS, Sem \bullet Sem', MT \circ sig(Sem') \rangle$$

$$\mathcal{L} \uplus \mathcal{L}' = \langle AS \circ AS', Sem \bullet Sem', MT \circ MT' \rangle$$

$$\mathcal{L} \oplus \mathcal{L}' = \langle AS \circ AS', Sem' \bullet Sem, MT'' \rangle \text{ where}$$
$$MT'' = MT \circ MT' \text{ and}$$
$$MT'' <: MT'$$

$$\Lambda_{-}^{+}(\mathcal{L}_1, c) = \langle AS_2, Sem_2, MT_2 \rangle, \text{ where:}$$
$$AS_2 \triangleq \lambda_{-}^{+}(AS_1, c),\ AS_2 \subseteq AS_1,$$
$$Sem_2 \triangleq \{A_i^t \in Sem_1, fp(A_i^t, AS_1) \subseteq AS_2\},$$
$$MT_1 <: MT_2,$$




```
language GuardedFsm {
    syntax 'FSM.ecore'
    syntax 'Guard.ecore'
    with ExecutableFsm
    with ExecutableState
    with ExecutableTransition
    with EvaluateGuard
    exactType GuardedFsmMT
}
```


SEMANTICS WEAVING

$$\mathcal{L} \triangleq \langle AS, Sem, MT \rangle$$

$$Sem(\mathcal{L}) \triangleq (A_i^t \in Aspects) \text{ where}$$
$$\forall A_i^t \in Sem(\mathcal{L}), \exists c \in AS(\mathcal{L}) : c \text{ match } t$$
$$\forall A_i^t, A_j^t \in Sem(\mathcal{L}) : A_i^t \lhd A_j^t \implies i > j$$

$$Sem \bullet Sem' \equiv Sem \frown Sem'$$

$$sig(Sem) \triangleq \mathop{\mathring{\bigcup}}_{A_i^t \in Sem} sig(A_i^t)$$

$$MT(\mathcal{L}) \triangleq AS(\mathcal{L}) \circ sig(Sem(\mathcal{L}))$$

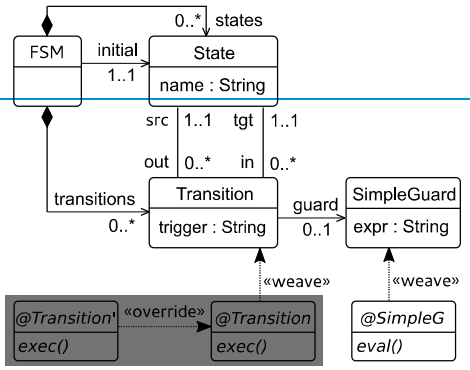
$$\mathcal{L} \xleftarrow{m} AS' = \langle AS \circ AS', Sem, MT \circ AS' \rangle$$

$$\mathcal{L} \xleftarrow{w} Sem' = \langle AS, Sem \bullet Sem', MT \circ sig(Sem') \rangle$$

$$\mathcal{L} \uplus \mathcal{L}' = \langle AS \circ AS', Sem \bullet Sem', MT \circ MT' \rangle$$

$$\mathcal{L} \oplus \mathcal{L}' = \langle AS \circ AS', Sem' \bullet Sem, MT'' \rangle \text{ where}$$
$$MT'' = MT \circ MT' \text{ and}$$
$$MT'' <: MT'$$

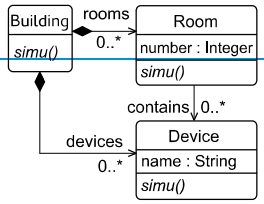
$$\Lambda_{-}^{+}(\mathcal{L}_1, c) = \langle AS_2, Sem_2, MT_2 \rangle, \text{ where:}$$
$$AS_2 \triangleq \lambda_{-}^{+}(AS_1, c),\ AS_2 \subseteq AS_1,$$
$$Sem_2 \triangleq \{A_i^t \in Sem_1, fp(A_i^t, AS_1) \subseteq AS_2\},$$
$$MT_1 <: MT_2,$$




```
language GuardedFsm {
    syntax 'FSM.ecore'
    syntax 'Guard.ecore'
    with ExecutableFsm
    with ExecutableState
    with ExecutableTransition
    with EvaluateGuard
    with OverrideTransition
    exactType GuardedFsmMT
}
```

LANGUAGE MERGING

$$\mathcal{L} \triangleq \langle AS, Sem, MT \rangle$$
$$Sem(\mathcal{L}) \triangleq (A_i^t \in Aspects) \text{ where}$$
$$\forall A_i^t \in Sem(\mathcal{L}), \exists c \in AS(\mathcal{L}) : c \text{ match } t$$
$$\forall A_i^t, A_j^t \in Sem(\mathcal{L}) : A_i^t \lhd A_j^t \implies i > j$$
$$Sem \bullet Sem' \equiv Sem \frown Sem'$$
$$sig(Sem) \triangleq \mathop{\overset{\circ}{\bigcup}}_{A_i^t \in Sem} sig(A_i^t)$$
$$MT(\mathcal{L}) \triangleq AS(\mathcal{L}) \circ sig(Sem(\mathcal{L}))$$
$$\mathcal{L} \xleftarrow{m} AS' = \langle AS \circ AS', Sem, MT \circ AS' \rangle$$
$$\mathcal{L} \xleftarrow{w} Sem' = \langle AS, Sem \bullet Sem', MT \circ sig(Sem') \rangle$$
$$\mathcal{L} \uplus \mathcal{L}' = \langle AS \circ AS', Sem \bullet Sem', MT \circ MT' \rangle$$
$$\mathcal{L} \oplus \mathcal{L}' = \langle AS \circ AS', Sem' \bullet Sem, MT'' \rangle \text{ where}$$
$$MT'' = MT \circ MT' \text{ and}$$
$$MT'' <: MT'$$
$$\Lambda_{-}^{+}(\mathcal{L}_1, c) = \langle AS_2, Sem_2, MT_2 \rangle, \text{ where:}$$
$$AS_2 \triangleq \lambda_{-}^{+}(AS_1, c),\ AS_2 \subseteq AS_1,$$
$$Sem_2 \triangleq \{A_i^t \in Sem_1, fp(A_i^t, AS_1) \subseteq AS_2\},$$
$$MT_1 <: MT_2,$$




```
language Building {
    syntax 'Building.ecore'
    with SimulatorAspect...

    exactType BuildingMT
}
```

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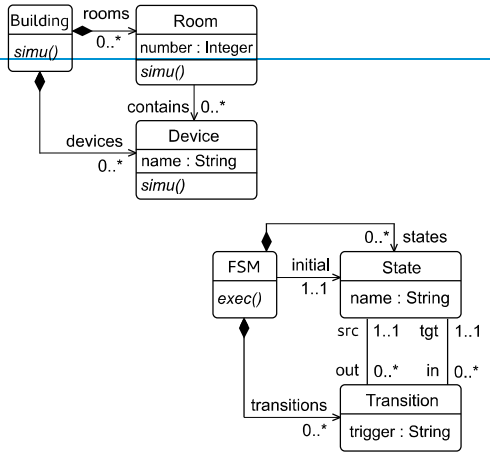
LANGUAGE MERGING

$$\mathcal{L} \triangleq \langle AS, Sem, MT \rangle$$
$$Sem(\mathcal{L}) \triangleq (A_i^t \in Aspects) \text{ where}$$
$$\forall A_i^t \in Sem(\mathcal{L}), \exists c \in AS(\mathcal{L}) : c \text{ match } t$$
$$\forall A_i^t, A_j^t \in Sem(\mathcal{L}) : A_i^t \lhd A_j^t \implies i > j$$
$$Sem \bullet Sem' \equiv Sem \frown Sem'$$
$$sig(Sem) \triangleq \mathop{\overset{\circ}{\bigcup}}_{A_i^t \in Sem} sig(A_i^t)$$
$$MT(\mathcal{L}) \triangleq AS(\mathcal{L}) \circ sig(Sem(\mathcal{L}))$$
$$\mathcal{L} \xleftarrow{m} AS' = \langle AS \circ AS', Sem, MT \circ AS' \rangle$$
$$\mathcal{L} \xleftarrow{w} Sem' = \langle AS, Sem \bullet Sem', MT \circ sig(Sem') \rangle$$
$$\mathcal{L} \uplus \mathcal{L}' = \langle AS \circ AS', Sem \bullet Sem', MT \circ MT' \rangle$$
$$\mathcal{L} \oplus \mathcal{L}' = \langle AS \circ AS^i, Sem^i \bullet Sem, MT^{iii} \rangle \text{ where}$$
$$MT'' = MT \circ MT' \text{ and}$$
$$MT'' <: MT'$$
$$\Lambda_{-}^{+}(\mathcal{L}_1, c) = \langle AS_2, Sem_2, MT_2 \rangle, \text{ where:}$$
$$AS_2 \triangleq \lambda_{-}^{+}(AS_1, c),\ AS_2 \subseteq AS_1,$$
$$Sem_2 \triangleq \{A_i^t \in Sem_1, fp(A_i^t, AS_1) \subseteq AS_2\},$$
$$MT_1 <: MT_2,$$




```
language Building {
    syntax 'Building.ecore'
    with SimulatorAspect...
    merge Fsm

    exactType BuildingMT
}
```

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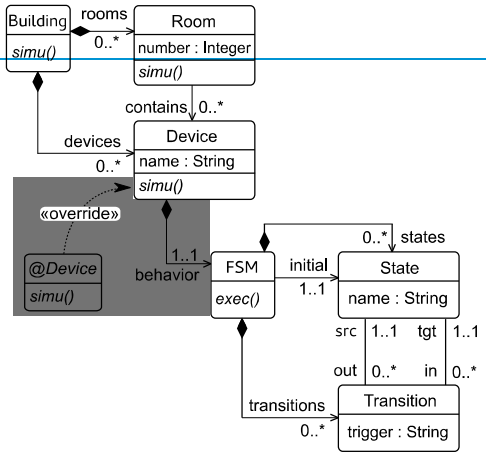
LANGUAGE MERGING

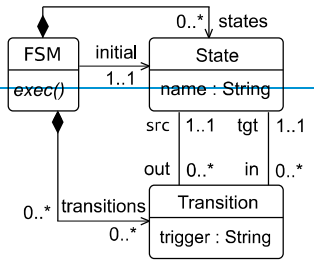
$$\mathcal{L} \triangleq \langle AS, Sem, MT \rangle$$
$$Sem(\mathcal{L}) \triangleq (A_i^t \in Aspects) \text{ where}$$
$$\forall A_i^t \in Sem(\mathcal{L}), \exists c \in AS(\mathcal{L}) : c \text{ match } t$$
$$\forall A_i^t, A_j^t \in Sem(\mathcal{L}) : A_i^t \lhd A_j^t \implies i > j$$
$$Sem \bullet Sem' \equiv Sem \frown Sem'$$
$$sig(Sem) \triangleq \mathop{\circ\!\!\bigcup}_{A_i^t \in Sem} sig(A_i^t)$$
$$MT(\mathcal{L}) \triangleq AS(\mathcal{L}) \circ sig(Sem(\mathcal{L}))$$
$$\mathcal{L} \xleftarrow{m} AS' = \langle AS \circ AS', Sem, MT \circ AS' \rangle$$
$$\mathcal{L} \xleftarrow{w} Sem' = \langle AS, Sem \bullet Sem', MT \circ sig(Sem') \rangle$$
$$\mathcal{L} \uplus \mathcal{L}' = \langle AS \circ AS', Sem \bullet Sem', MT \circ MT' \rangle$$
$$\mathcal{L} \oplus \mathcal{L}' = \langle AS \circ AS', Sem' \bullet Sem, MT'' \rangle \text{ where}$$
$$MT'' = MT \circ MT' \text{ and}$$
$$MT'' <: MT'$$
$$\Lambda_{-}^{+}(\mathcal{L}_1, c) = \langle AS_2, Sem_2, MT_2 \rangle, \text{ where:}$$
$$AS_2 \triangleq \lambda_{-}^{+}(AS_1, c),\ AS_2 \subseteq AS_1,$$
$$Sem_2 \triangleq \{A_i^t \in Sem_1, fp(A_i^t, AS_1) \subseteq AS_2\},$$
$$MT_1 <: MT_2,$$




```
language Building {
    syntax 'Building.ecore'
    with SimulatorAspect...
    merge Fsm
    with GlueDeviceToFsm
    exactType BuildingMT
}
```


LANGUAGE INHERITANCE

$$\mathcal{L} \triangleq \langle AS, Sem, MT \rangle$$
$$Sem(\mathcal{L}) \triangleq (A_i^t \in Aspects) \text{ where}$$
$$\forall A_i^t \in Sem(\mathcal{L}), \exists c \in AS(\mathcal{L}) : c \text{ match } t$$
$$\forall A_i^t, A_j^t \in Sem(\mathcal{L}) : A_i^t \lhd A_j^t \implies i > j$$
$$Sem \bullet Sem' \equiv Sem \frown Sem'$$
$$sig(Sem) \triangleq \mathop{\circ\!\!\bigcup}_{A_i^t \in Sem} sig(A_i^t)$$
$$MT(\mathcal{L}) \triangleq AS(\mathcal{L}) \circ sig(Sem(\mathcal{L}))$$
$$\mathcal{L} \xleftarrow{m} AS' = \langle AS \circ AS', Sem, MT \circ AS' \rangle$$
$$\mathcal{L} \xleftarrow{w} Sem' = \langle AS, Sem \bullet Sem', MT \circ sig(Sem') \rangle$$
$$\mathcal{L} \uplus \mathcal{L}' = \langle AS \circ AS', Sem \bullet Sem', MT \circ MT' \rangle$$
$$\mathcal{L} \oplus \mathcal{L}' = \langle AS \circ AS', Sem' \bullet Sem, MT'' \rangle \text{ where}$$
$$MT'' = MT \circ MT' \text{ and}$$
$$MT'' <: MT'$$
$$\Lambda_{-}^{+}(\mathcal{L}_1, c) = \langle AS_2, Sem_2, MT_2 \rangle, \text{ where:}$$
$$AS_2 \triangleq \lambda_{-}^{+}(AS_1, c),\ AS_2 \subseteq AS_1,$$
$$Sem_2 \triangleq \{A_i^t \in Sem_1, fp(A_i^t, AS_1) \subseteq AS_2\},$$
$$MT_1 <: MT_2,$$




```
language TimedFsm inherits Fsm {

    exactType TimedFsmMT
}
```

LANGUAGE INHERITANCE

$$\mathcal{L} \triangleq \langle AS, Sem, MT \rangle$$

$$Sem(\mathcal{L}) \triangleq (A_i^t \in Aspects) \text{ where}$$
$$\forall A_i^t \in Sem(\mathcal{L}), \exists c \in AS(\mathcal{L}) : c \text{ match } t$$
$$\forall A_i^t, A_j^t \in Sem(\mathcal{L}) : A_i^t \lhd A_j^t \implies i > j$$

$$Sem \bullet Sem' \equiv Sem \frown Sem'$$

$$sig(Sem) \triangleq \overset{\circ}{\bigcup_{A_i^t \in Sem}} sig(A_i^t)$$

$$MT(\mathcal{L}) \triangleq AS(\mathcal{L}) \circ sig(Sem(\mathcal{L}))$$

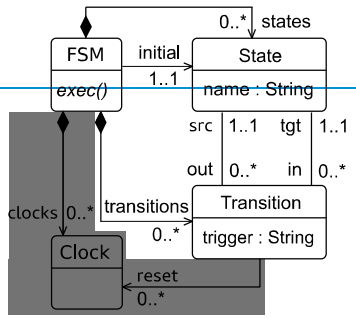
$$\mathcal{L} \overset{m}{\leftarrow} AS' = \langle AS \circ AS', Sem, MT \circ AS' \rangle$$

$$\mathcal{L} \overset{w}{\leftarrow} Sem' = \langle AS, Sem \bullet Sem', MT \circ sig(Sem') \rangle$$

$$\mathcal{L} \uplus \mathcal{L}' = \langle AS \circ AS', Sem \bullet Sem', MT \circ MT' \rangle$$

$$\mathcal{L} \oplus \mathcal{L}' = \langle AS \circ AS', Sem' \bullet Sem, MT'' \rangle \text{ where}$$
$$MT'' = MT \circ MT' \text{ and}$$
$$MT'' <: MT'$$

$$\Lambda_{-}^{+}(\mathcal{L}_1, c) = \langle AS_2, Sem_2, MT_2 \rangle, \text{ where:}$$
$$AS_2 \triangleq \lambda_{-}^{+}(AS_1, c),\ AS_2 \subseteq AS_1,$$
$$Sem_2 \triangleq \{A_i^t \in Sem_1, fp(A_i^t, AS_1) \subseteq AS_2\},$$
$$MT_1 <: MT_2,$$




```
language TimedFsm inherits Fsm {
        syntax 'Clocks.ecore'

        exactType TimedFsmMT
                }
```


LANGUAGE INHERITANCE

$$\mathcal{L} \triangleq \langle AS, Sem, MT \rangle$$

$$Sem(\mathcal{L}) \triangleq (A_i^t \in Aspects) \text{ where}$$
$$\forall A_i^t \in Sem(\mathcal{L}), \exists c \in AS(\mathcal{L}) : c \text{ match } t$$
$$\forall A_i^t, A_j^t \in Sem(\mathcal{L}) : A_i^t \lhd A_j^t \implies i > j$$

$$Sem \bullet Sem' \equiv Sem \frown Sem'$$

$$sig(Sem) \triangleq \overset{\circ}{\bigcup_{A_i^t \in Sem}} sig(A_i^t)$$

$$MT(\mathcal{L}) \triangleq AS(\mathcal{L}) \circ sig(Sem(\mathcal{L}))$$

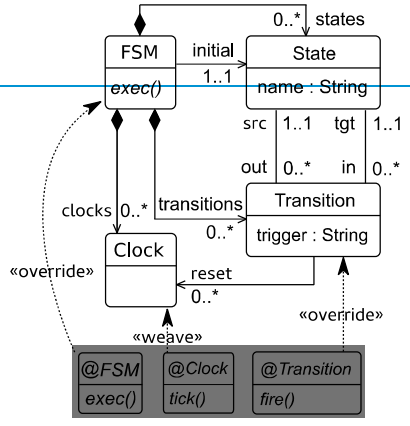
$$\mathcal{L} \overset{m}{\leftarrow} AS' = \langle AS \circ AS', Sem, MT \circ AS' \rangle$$

$$\mathcal{L} \overset{w}{\leftarrow} Sem' = \langle AS, Sem \bullet Sem', MT \circ sig(Sem') \rangle$$

$$\mathcal{L} \uplus \mathcal{L}' = \langle AS \circ AS', Sem \bullet Sem', MT \circ MT' \rangle$$

$$\mathcal{L} \oplus \mathcal{L}' = \langle AS \circ AS', Sem' \bullet Sem, MT'' \rangle \text{ where}$$
$$MT'' = MT \circ MT' \text{ and}$$
$$MT'' <: MT'$$

$$\Lambda_{-}^{+}(\mathcal{L}_1, c) = \langle AS_2, Sem_2, MT_2 \rangle, \text{ where:}$$
$$AS_2 \triangleq \lambda_{-}^{+}(AS_1, c),\ AS_2 \subseteq AS_1,$$
$$Sem_2 \triangleq \{A_i^t \in Sem_1, fp(A_i^t, AS_1) \subseteq AS_2\},$$
$$MT_1 <: MT_2,$$




```
language TimedFsm inherits Fsm {
        syntax 'Clocks.ecore'
            with ClockTick
            with OverrideFsm
        with OverrideTransition
            exactType TimedFsmMT
                }
```

LANGUAGE SLICING

$\mathcal{L} \triangleq \langle AS, Sem, MT \rangle$

$Sem(\mathcal{L}) \triangleq (A_i^t \in Aspects)$ where

$\forall A_i^t \in Sem(\mathcal{L}), \exists c \in AS(\mathcal{L}) : c \text{ match } t$

$\forall A_i^t, A_j^t \in Sem(\mathcal{L}) : A_i^t \lhd A_j^t \implies i > j$

$Sem \bullet Sem' \equiv Sem \frown Sem'$

$sig(Sem) \triangleq \overset{\circ}{\bigcup_{A_i^t \in Sem}} sig(A_i^t)$

$MT(\mathcal{L}) \triangleq AS(\mathcal{L}) \circ sig(Sem(\mathcal{L}))$

$\mathcal{L} \xleftarrow{m} AS' = \langle AS \circ AS', Sem, MT \circ AS' \rangle$

$\mathcal{L} \xleftarrow{w} Sem' = \langle AS, Sem \bullet Sem', MT \circ sig(Sem') \rangle$

$\mathcal{L} \uplus \mathcal{L}' = \langle AS \circ AS', Sem \bullet Sem', MT \circ MT' \rangle$

$\mathcal{L} \oplus \mathcal{L}' = \langle AS \circ AS', Sem' \bullet Sem, MT'' \rangle$ where

$MT'' = MT \circ MT'$ and

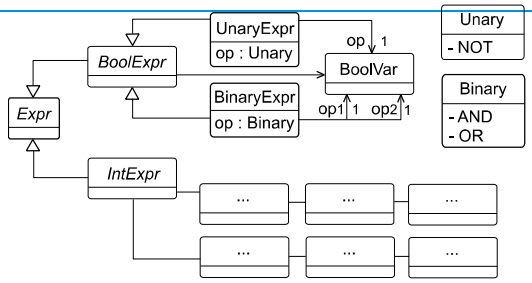
$MT'' <: MT'$

$\Lambda^+_-(\mathcal{L}_1, c) = \langle AS_2, Sem_2, MT_2 \rangle$, where:

$AS_2 \triangleq \lambda^+_-(AS_1, c),\ AS_2 \subseteq AS_1,$

$Sem_2 \triangleq \{A_i^t \in Sem_1, fp(A_i^t, AS_1) \subseteq AS_2\},$

$MT_1 <: MT_2,$




```
language Expressions {
syntax 'Expressions.ecore'
   with EvaluateBoolean
   with EvaluateInteger
 exactType ExpressionsMT
          }
```


LANGUAGE SLICING

$\mathcal{L} \triangleq \langle AS, Sem, MT \rangle$

$Sem(\mathcal{L}) \triangleq (A_i^t \in Aspects)$ where

$\forall A_i^t \in Sem(\mathcal{L}), \exists c \in AS(\mathcal{L}) : c \text{ match } t$

$\forall A_i^t, A_j^t \in Sem(\mathcal{L}) : A_i^t \lhd A_j^t \implies i > j$

$Sem \bullet Sem' \equiv Sem \frown Sem'$

$sig(Sem) \triangleq \overset{\circ}{\bigcup_{A_i^t \in Sem}} sig(A_i^t)$

$MT(\mathcal{L}) \triangleq AS(\mathcal{L}) \circ sig(Sem(\mathcal{L}))$

$\mathcal{L} \xleftarrow{m} AS' = \langle AS \circ AS', Sem, MT \circ AS' \rangle$

$\mathcal{L} \xleftarrow{w} Sem' = \langle AS, Sem \bullet Sem', MT \circ sig(Sem') \rangle$

$\mathcal{L} \uplus \mathcal{L}' = \langle AS \circ AS', Sem \bullet Sem', MT \circ MT' \rangle$

$\mathcal{L} \oplus \mathcal{L}' = \langle AS \circ AS', Sem' \bullet Sem, MT'' \rangle$ where

$MT'' = MT \circ MT'$ and

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$\Lambda^+_-(\mathcal{L}_1, c) = \langle AS_2, Sem_2, MT_2 \rangle$, where:

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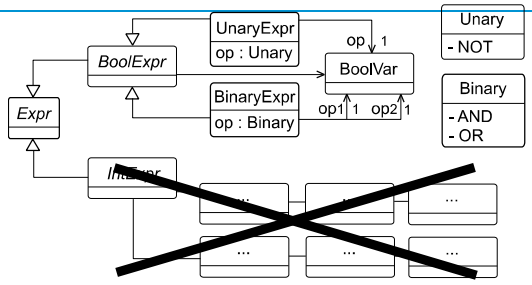
$MT_1 <: MT_2,$




```
language Expressions {
syntax 'Expressions.ecore'
   with EvaluateBoolean
   with EvaluateInteger
 exactType ExpressionsMT
          }

language BooleanExpressions {
      slice Expressions on
        ['BoolExpr']
 exactType BooleanExpressionsMT
          }
```

LANGUAGE SLICING

$$\mathcal{L} \triangleq \langle AS, Sem, MT \rangle$$

$$Sem(\mathcal{L}) \triangleq (A_i^t \in Aspects) \text{ where}$$
$$\forall A_i^t \in Sem(\mathcal{L}), \exists c \in AS(\mathcal{L}) : c \text{ match } t$$
$$\forall A_i^t, A_j^t \in Sem(\mathcal{L}) : A_i^t \lhd A_j^t \implies i > j$$

$$Sem \bullet Sem' \equiv Sem \frown Sem'$$

$$sig(Sem) \triangleq \mathop{\mathring{\bigcup}}_{A_i^t \in Sem} sig(A_i^t)$$

$$MT(\mathcal{L}) \triangleq AS(\mathcal{L}) \circ sig(Sem(\mathcal{L}))$$

$$\mathcal{L} \xleftarrow{m} AS' = \langle AS \circ AS', Sem, MT \circ AS' \rangle$$

$$\mathcal{L} \xleftarrow{w} Sem' = \langle AS, Sem \bullet Sem', MT \circ sig(Sem') \rangle$$

$$\mathcal{L} \uplus \mathcal{L}' = \langle AS \circ AS', Sem \bullet Sem', MT \circ MT' \rangle$$

$$\mathcal{L} \oplus \mathcal{L}' = \langle AS \circ AS', Sem' \bullet Sem, MT'' \rangle \text{ where}$$
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$$\Lambda_{-}^{+}(\mathcal{L}_1, c) = \langle AS_2, Sem_2, MT_2 \rangle, \text{ where:}$$
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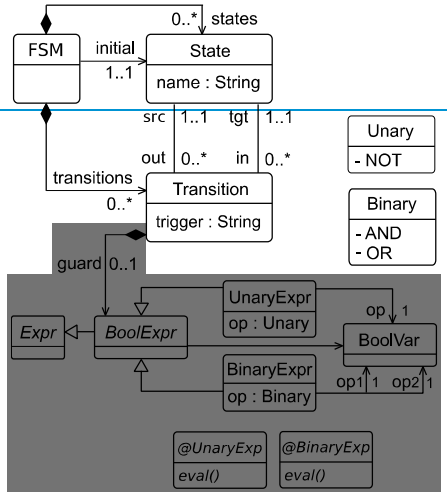
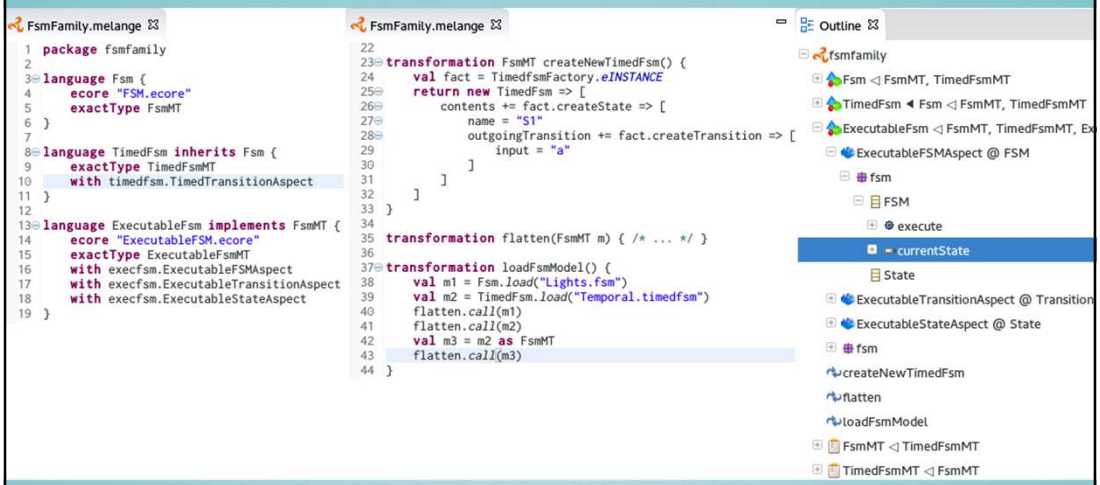



```
language GuardedFsm inherits Fsm {
        with ...
    merge BooleanExpressions
    with AttachGuardToTransition
     exactType GuardedFsmMT
}
```

IRISA UMR



Melange

A Language Workbench

MELANGE

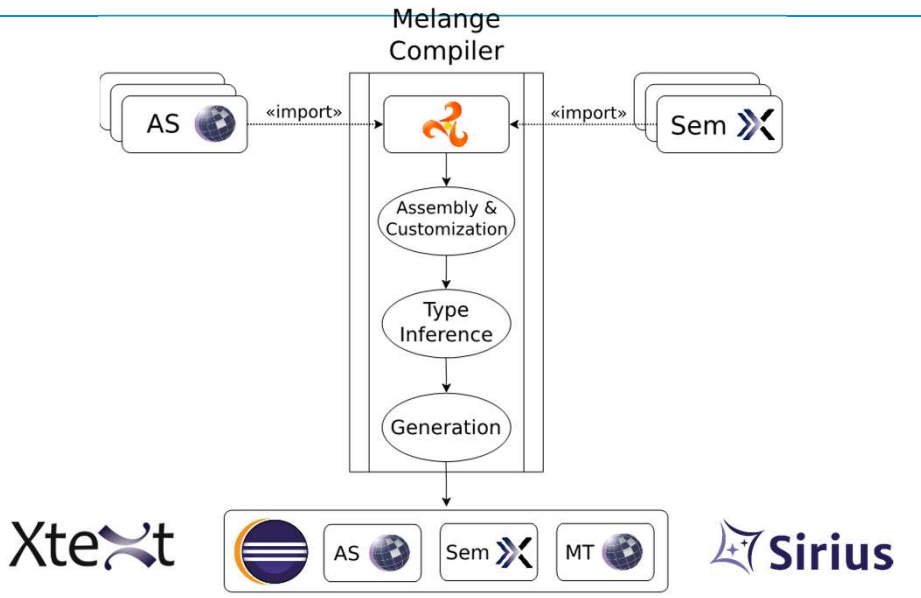
- An open-source (EPL) language workbench
- or… a language-based, model-oriented language for DSL engineering
- An implementation of the algebra
- Supported by a model-oriented type sytem
- Based on Xtext
- Seamlessly integrated with the EMF ecosystem
- Bundled as a set of Eclipse plug-ins

Implementation Choices

- **Abstract syntax**: Ecore (EMOF)
- **Merging**: Customized UML PackageMerge[1]
  - Trading UML specificities with EMOF specificities
  - Support for renaming
- **Slicing**: Kompren[2]
- **Operational semantics**: K3 (Xtend on steroids)

1 Dingel *et al.*, *Understanding and Improving UML PackageMerge*, SoSyM, 2008
2 Blouin *et al.*, *Kompren: Modeling and generating model slicers*, SoSyM, 2012

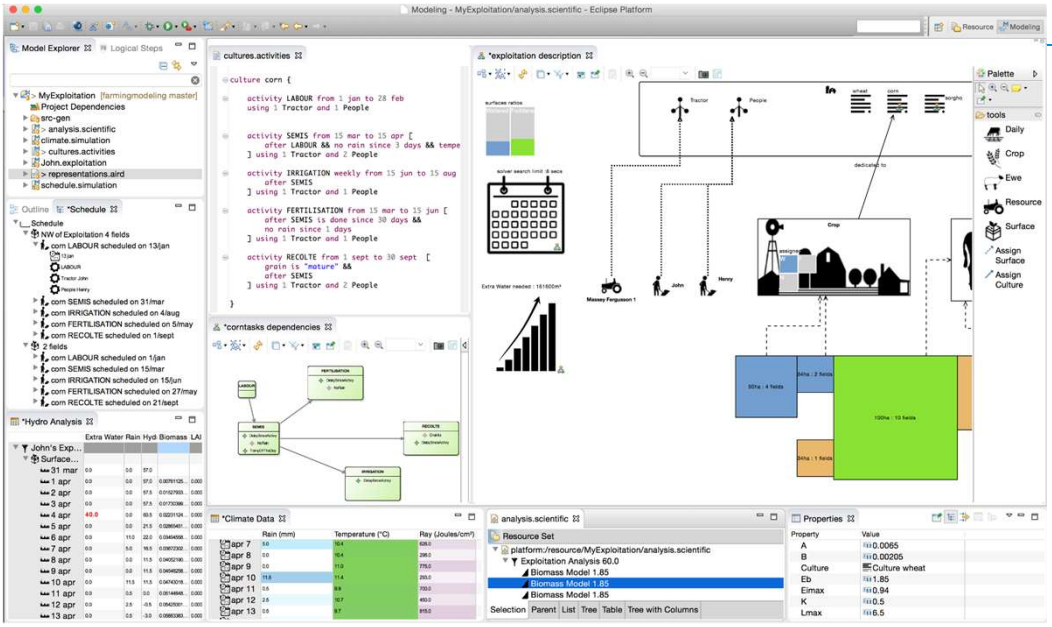
Compilation Scheme



OK, but does it work in practice?

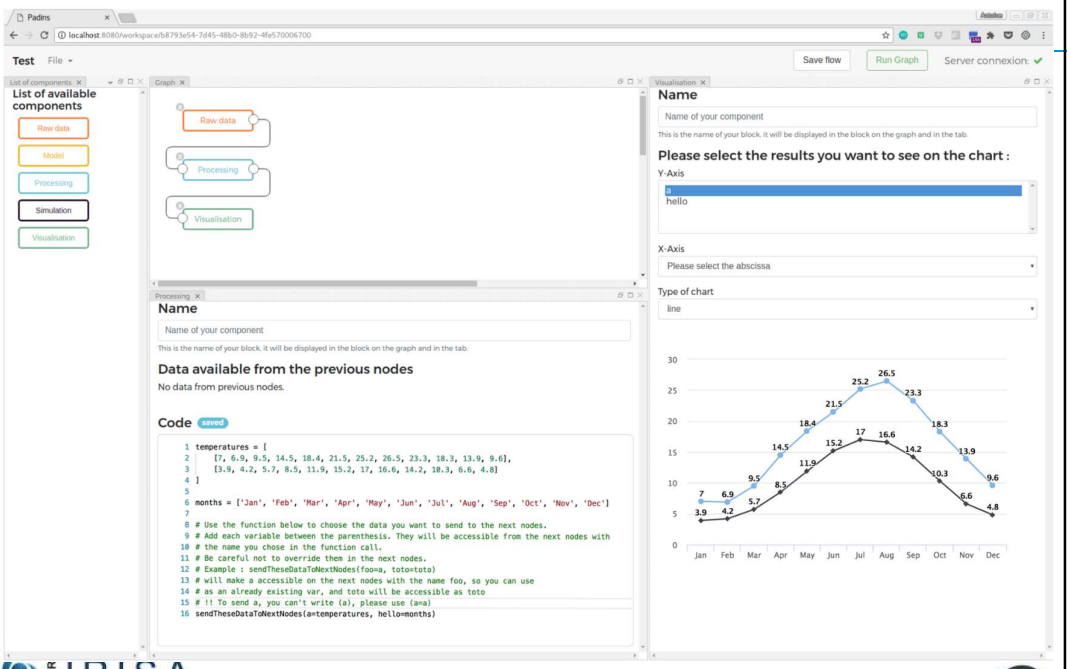
Talk is cheap, show me the code!
[Linus Torvalds]

Farming System Modeling (/ Software Defined Farming)



UMR IRISA **https://github.com/gemoc/farmingmodeling**

Water flood prediction

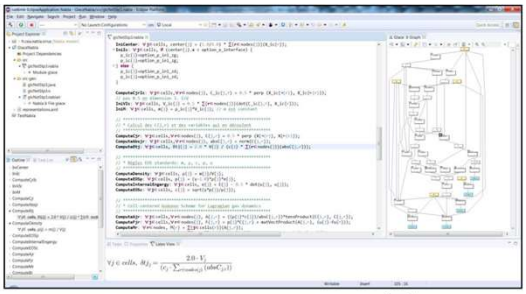


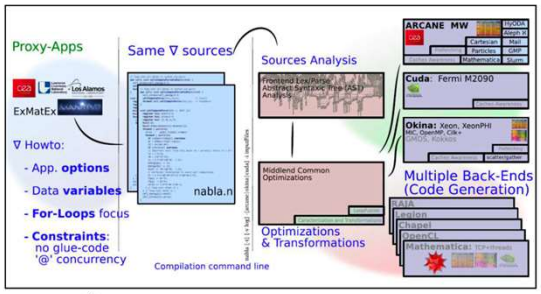
UMR IRISA

High Performance Computing

Nablab Environment
Technologies : Eclipse EMF, Xtext, Sirius
Contributors : MPO, BL, BC

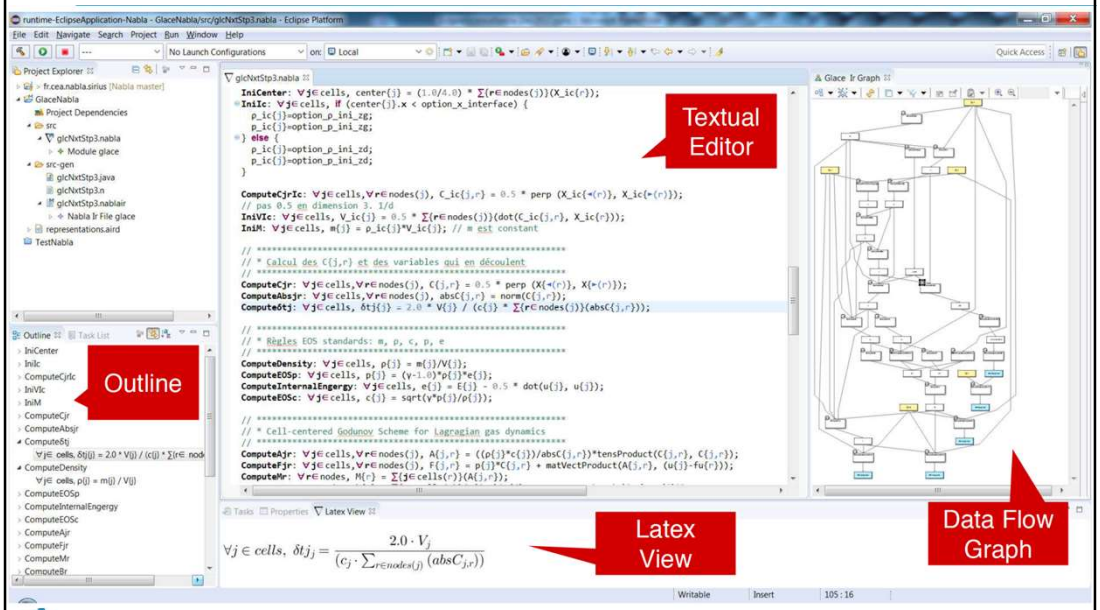
Nabla Language
Technologies : Flex, Bison, C++
Contributors : JSC, BL





Nabla text files (.n)

High Performance Computing



Open Challenges

- Diversity/complexity of DSL relationships
  - Far beyond structural/behavioral alignment, refinement, decomposition
  - Separation of concerns vs. Zoom-in/Zoom-out
- Live and collaborative (meta)modeling
  - Minimize the round trip between the DSL specification, the model, and its application (interpretation/compilation)
  - Model experiencing environments (MEEs): what-if/for scenarios, trade-off analysis, design-space exploration
- Integration of analysis and predictive models into DSL semantics
  - Towards unpredictable languages
    - Specify the correctness envelope to avoid over-specification
    - Identify plastic computation zones
    - Vary the execution flow of the program

Conclusion

- From supporting a single DSL…
  - Concrete syntax, abstract syntax, semantics, pragmatics
    - Editors, Parsers, Simulators, Compilers…
    - But also: Checkers, Refactoring tools, Converters…
- …To supporting Multiple DSLs
  - Interacting altogether
  - Each DSL with several flavors: families of DSLs
  - And evolving over time
- **Product Lines of DSLs**
  - Share and reuse assets: metamodels and transformations

Acknowledgement

- All these ideas have been developed with my colleagues of the DiverSE team at IRISA/Inria

DiverSE
Diversity-Centric Software Engineering

Formely known as Triskell

IRISA UMR

@jmjezequel

CHAPMAN & HALL/CRC INNOVATIONS IN SOFTWARE ENGINEERING AND SOFTWARE DEVELOPMENT

Engineering Modeling Languages

Turning Domain Knowledge into Tools

Benoit Combemale
Robert B. France
Jean-Marc Jézéquel
Bernhard Rumpe
Jim Steel
Didier Vojtisek

CRC Press
Taylor & Francis Group
A CHAPMAN & HALL BOOK