Towards a DSL for formalising laws and regulations

intermediate findings and results

L. Thomas van Binsbergen

Informatics Institute, University of Amsterdam
ltvanbinsbergen@acm.org

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UNIVERSITY OF AMSTERDAM

Overview

1. Regulated systems
   Relating normative and computational concepts

2. The eFLINT language
   eFLINT 1.0
   eFLINT 2.0
   Goals for eFLINT 3.0

3. Reflections

Section 1

Regulated systems

Towards regulated systems

Monolithic programs

Towards regulated systems

Monolithic programs $\xrightarrow{\textit{distribution}}$ Service-oriented architectures

Towards regulated systems

$$\begin{array}{ccc}\text{Monolithic programs} & \xrightarrow{\textit{distribution}} & \text{Service-oriented architectures}\\ \Big\downarrow{\scriptstyle \textit{AI}} & & \\ \text{Autonomous systems} & & \end{array}$$

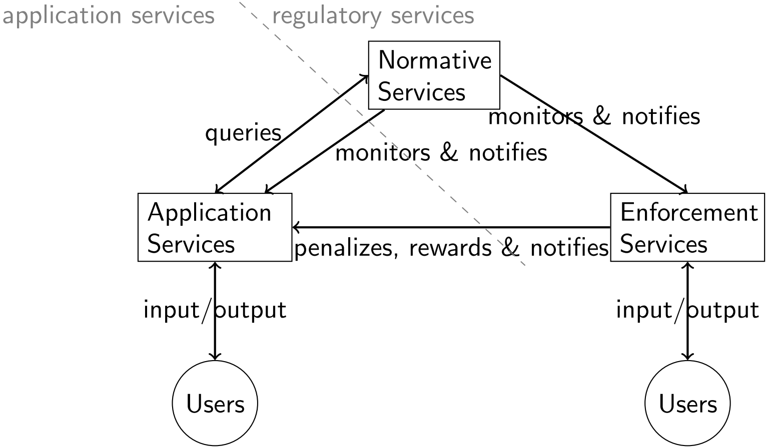
Towards regulated systems

$$
\begin{tikzcd}
\text{Monolithic programs} \arrow[r, "\textit{distribution}"] \arrow[d, "\textit{AI}"] & \text{Service-oriented architectures} \arrow[d, "\textit{AI}"] \\
\text{Autonomous systems} \arrow[r, "\textit{distribution}"] & \text{Social software systems}
\end{tikzcd}
$$

Towards regulated systems

$$
\begin{tikzcd}
\text{Monolithic programs} \arrow[r, "\textit{distribution}"] \arrow[d, "\textit{AI}"] & \text{Service-oriented architectures} \arrow[d, "\textit{AI}"] & \\
\text{Autonomous systems} \arrow[r, "\textit{distribution}"] & \text{Social software systems} \arrow[dr, "\textit{norms} + \textit{enforcement}"] & \\
& & \text{Regulated (software) systems}
\end{tikzcd}
$$

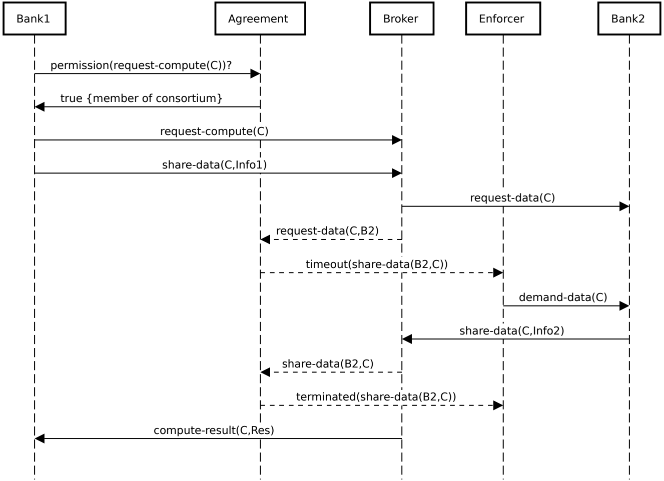
Regulated system = application services + regulatory services



Dynamic enforcement examples – sharing agreement

(Article 1) A member of the consortium has the right to request a risk assessment computation from the broker for any (potential) client

(Article 2) The data broker has the power to oblige members of the consortium to share information about any client the member does business with



Our approach to model-driven experimentation

eFLINT – formalization of norms from a variety of sources

declarative reasoning about facts, actions and duties

reactive component for integration in software systems

including actor-based implementation

AgentScriptCC – specification of services as agents

reactive BDI agents,

compiled to actor-based implementation

Actor-oriented programming in the Akka framework:

`https://akka.io/`

actor systems modelling social software systems

eFLINT: A Domain-Specific Language for Executable Norm Specifications

L. Thomas van Binsbergen
Centrum Wiskunde & Informatica
Amsterdam, The Netherlands
ltvanbinsbergen@acm.org

Lu-Chi Liu
University of Amsterdam
Amsterdam, The Netherlands
l.liu@uva.nl

Robert van Doesburg
Leibniz Institute, University of Amsterdam / TNO
Amsterdam, The Netherlands
robertvandoesburg@uva.nl

Tom van Engers
Leibniz Institute, University of Amsterdam / TNO
Amsterdam, The Netherlands
vanengers@uva.nl

published @ SPLASH 2020

Run, Agent, Run

Architecture and Benchmarking of Actor-based Agents

Mostafa Mohajeri Parizi
m.mohajeriparizi@uva.nl
Informatics Institute, University of Amsterdam
Amsterdam, the Netherlands

Giovanni Sileno
g.sileno@uva.nl
Informatics Institute, University of Amsterdam
Amsterdam, the Netherlands

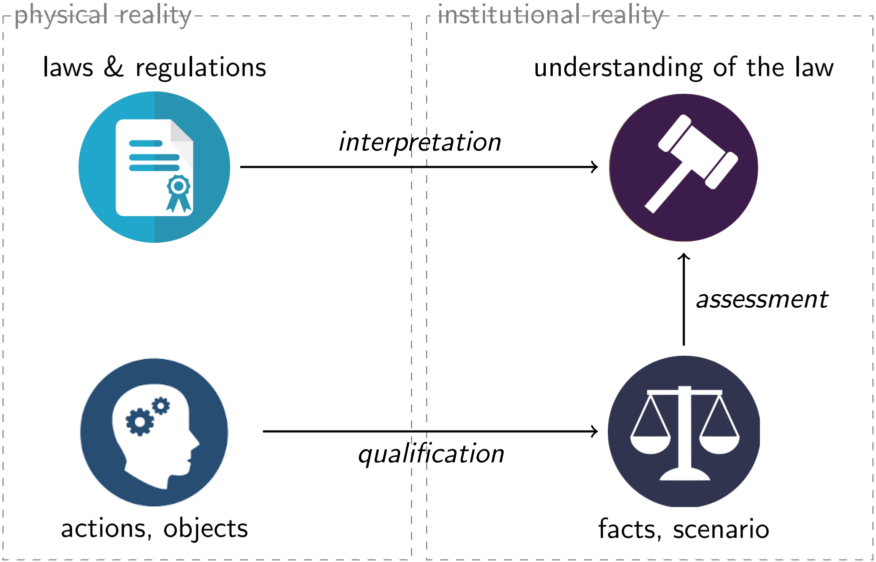
Tom van Engers
vanengers@uva.nl
Informatics Institute, University of Amsterdam
Amsterdam, the Netherlands

Sander Klous
s.klous@uva.nl
Informatics Institute, University of Amsterdam
Amsterdam, the Netherlands

published @ SPLASH 2020

Subsection 1

Relating normative and computational concepts



"If the facts are against you, argue the law. If the law is against you, argue the facts. If the law and the facts are against you, pound the table ..." -Carl Sandburg

Foundational, normative & computational concepts

computational

state

$$\boxed{\begin{array}{l} parent(A, B) = true \\ \ldots \end{array}}$$

Foundational, normative & computational concepts

computational

state

$parent(A, B) = true$
$\ldots$

transitions

$parent(A, B) = true$
$\ldots$

$parent(A, B) = false$
$\ldots$

Foundational, normative & computational concepts

computational

state

$parent(A, B) = true$
$\ldots$

transitions

$parent(A, B) = true$
$\ldots$

$parent(A, B) = false$
$\ldots$

- Violations of state and transition

Foundational, normative & computational concepts

deontic

prohibitions

permissions

obligations

computational

state

$parent(A, B) = true$
$\ldots$

transitions

$parent(A, B) = true$
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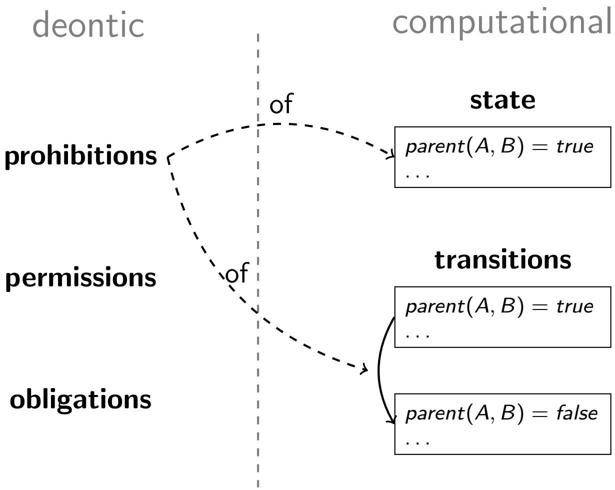
$parent(A, B) = false$
$\ldots$

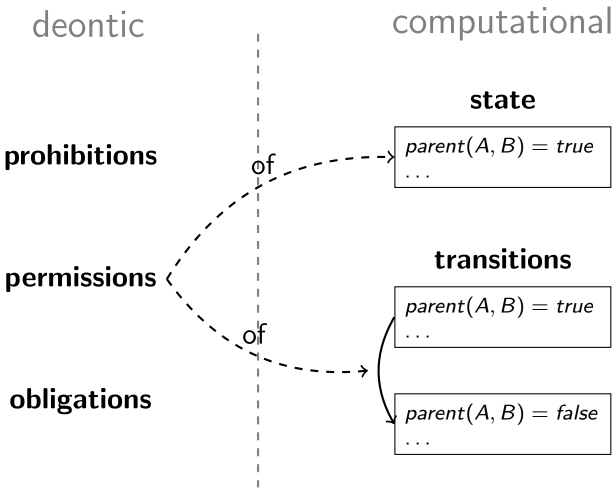
- Violations of state and transition

Foundational, normative & computational concepts



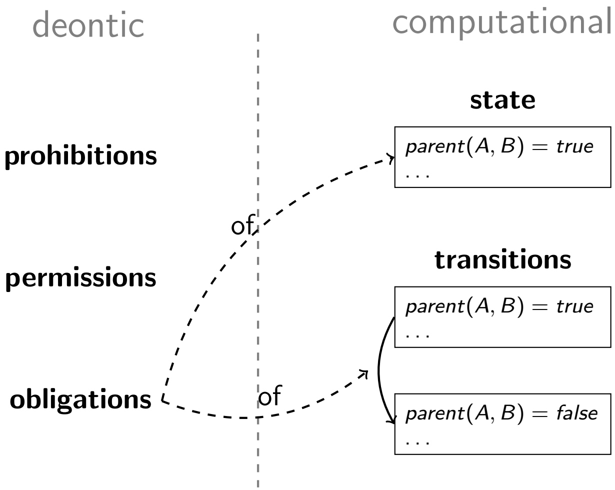
- Violations of state and transition

Foundational, normative & computational concepts



- Violations of state and transition

Foundational, normative & computational concepts



- Violations of state and transition

Foundational, normative & computational concepts

deontic

computational

potestative

state

$parent(A, B) = true$
$\ldots$

prohibitions

powers

of

transitions

permissions

$parent(A, B) = true$
$\ldots$

obligations

of

$parent(A, B) = false$
$\ldots$

▪Violations of state and transition

Foundational, normative & computational concepts

deontic

prohibitions

permissions

obligations

of

of

computational

state

$parent(A, B) = true$
...

transitions

$parent(A, B) = true$
...

$parent(A, B) = false$
...

- Violations of state and transition

potestative

powers

- Powers have (normative) consequences

Foundational, normative & computational concepts

deontic | computational | potestative

prohibitions

permissions

obligations

of

of

state

$parent(A, B) = true$ $\ldots$

transitions

$parent(A, B) = true$ $\ldots$

$parent(A, B) = false$ $\ldots$

- Violations of state and transition

powers

- Powers have (normative) consequences
- Deontic and potestative terms are first-class
- Powers modify truth-assignments to variables

Foundational, normative & computational concepts

deontic

prohibitions

permissions

obligations

of

of

computational

state

$parent(A, B) = true$
...

transitions

$parent(A, B) = true$
...

$parent(A, B) = false$
...

- Violations of state and transition

potestative

powers

- Powers have (normative) consequences
  - Deontic and potestative terms are first-class
  - Powers modify truth-assignments to variables
- Explicit permissions cause conflicts

Normative relations between actors

- A deontic value is associated with several actors:
  - The **holder** of the prohibition, obligation or prohibition
  - Zero or more **claimants** to the prohibition or obligation
  - The actor who **assigned** the prohibition, obligation or permission
- A potestative value is associated with several actors
  - The **performing** actor
  - One or more **recipients** being affected by the power
  - The actor who **assigned** the power

Regulated systems – points to address

Formalization of applicable norms: reusable, modular and dynamically updateable

Different methods of embedding and enforcing norms:

- Static ex-ante: verify and apply norms during software production
  e.g. correct-by-construction arguments, model checking
- Dynamic ex-ante: apply rules at run-time, guaranteeing compliance
  enables decisions (behavioral, normative) that depend on input
- Embedded ex-post enforcement: specified responses to violations
  enables (regulated) non-compliant behavior, e.g. based on risk assessment by agent
- External ex-post enforcement: external responses to violations
  e.g. auditing, conformance checking
  enables (human-)intervention in running system

Production of diagnostic reports and/or audit trails to enable evaluation and reflection

Regulated *systems* – points to address

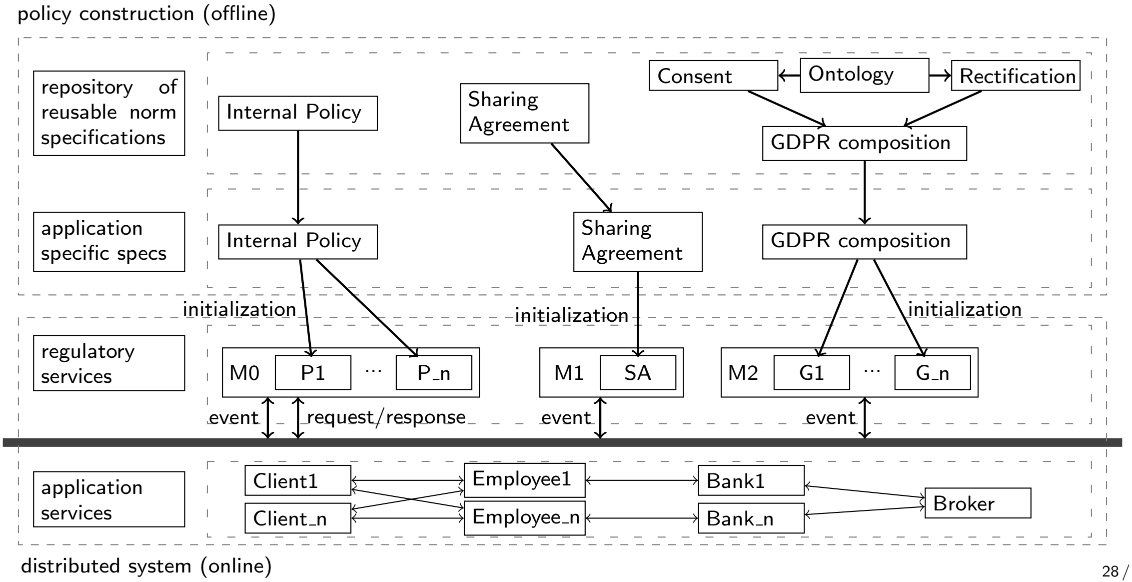
Derivation of regulatory services from formalization of norms

Interfacing between application and regulatory services:

- Monitoring (communicated and silent) behavior of services
  difficulties: fallible and subject to manipulation
- Regulatory services responding to queries about normative positions
  e.g. do I have permission to...? or the obligation to... ?
- Application services verifying facts on behalf of regulatory services
  e.g. verifying credentials or certificates
- Regulatory services communicating changes in normative positions
  e.g. gaining/losing powers, holding/satisfying obligations, violations

Challenges: different interpretations of norms and different qualifications of situations

Regulated systems for Know Your Customer case study



Section 2

The eFLINT language

Subsection 1

eFLINT 1.0

Example – knowledge representation

(Toy Article 1) a natural person is a legal parent of another natural person if:

- *they are a natural parent, or*
- *they are an adoptive parent*

```
Fact person Identified by String
Placeholder parent    For person
Placeholder child     For person

Fact natural-parent   Identified by parent * child
Fact adoptive-parent  Identified by parent * child

Fact legal-parent     Identified by parent * child
  Holds when adoptive-parent(parent,child)
          || natural-parent(parent,child)
```

Example – powers and duties

(Toy Article 2) a child has the power to ask a legal parent for help with their homework, resulting in a duty for the parent to help.

```
Act ask-for-help
  Actor       child
  Recipient   parent
  Creates     help-with-homework(parent,child)
  Holds when  legal-parent(parent,child)

Duty help-with-homework
  Holder         parent
  Claimant       child
  Violated when  homework-due(child)

Fact homework-due Identified by child

Act help
  Actor       parent
  Recipient   child
  Terminates  help-with-homework(parent,child)
  Holds when  help-with-homework(parent,child)
```

Example – scenario

```
Fact person Identified by Alice, Bob, Chloe, David
```

Listing 1: Domain specification

```
+natural-parent(Alice, Bob).
+adoptive-parent(Chloe, David).
```

Listing 2: Initial state

```
ask-for-help(Bob, Alice).                    // Alice is Bob's legal parent
+homework-due(Bob).                          // homework deadline passed
?Violated(help-with-homework(Alice,Bob)).    // query duty violation
help(Alice,Bob).                             // duty terminated
```

Listing 3: Scenario

eFLINT online!

frames

```
Fact person Identified by String
Placeholder parent    For person
Placeholder child     For person

Fact natural-parent   Identified by parent * child
Fact adoptive-parent  Identified by parent * child
Fact legal-parent     Identified by parent * child
  Holds when adoptive-parent(parent,child)
          || natural-parent(parent,child)

Act ask-for-help
  Actor      child
  Recipient  parent
  Creates    help-with-homework(parent,child)
  Holds when legal-parent(parent,child)

Fact homework-due Identified by child

Duty help-with-homework
  Holder        parent
  Claimant      child
  Violated when homework-due(child)

Act help
  Actor      parent
  Recipient  child
  Terminates help-with-homework(parent,child)
  Holds when help-with-homework(parent,child)
```

domains

```
Fact person Identified by Alice, Bob, Chloe, David
```

initial state

```
natural-parent(Alice, Bob).
adoptive-parent(Chloe, David).
```

Examples

Knowledge representation: Vehicles | Departments | Count Votes | Cast Votes
GPCE2020 paper examples: Help with homework | GDPR
Various: Buyer/Seller (v1) | Buyer/Seller (v2) | Buyer/Seller (v3) | Permit Applications | Permit Applications (v2) | Multiple taxpayers | Voting
Load file: Browse... No file selected.

scenario

```
ask-for-help(Bob, Alice).
+homework-due(Bob).  // homework deadline passed
?Violated(help-with-homework(Alice,Bob)).
help(Alice,Bob).
```

Run | Reset | Save | model name

response

```
* Duty violated at step 2
    ("Alice":person,"Bob":person):help-with-homework
```

output

Step 0: initial state

Step 1: ("Bob":person,"Alice":person):ask-for-help
+("Alice":person,"Bob":person):help-with-homework

Step 2: ("Bob":person):homework-due
+("Bob":person):homework-due

Step 3: query

Step 4: ("Alice":person,"Bob":person):help
-("Alice":person,"Bob":person):help-with-homework

Subsection 2

eFLINT 2.0

Deriving REPLs and Notebooks for DSLs – ALE collaboration

From DSL Specification to Interactive Computer Programming Environment

Pierre Jeanjean
Inria, Univ Rennes, CNRS, IRISA
Rennes, France
pierre.jeanjean@inria.fr

Benoit Combemale
University of Toulouse
Toulouse, France
benoit.combemale@irit.fr

Olivier Barais
Univ Rennes, Inria, CNRS, IRISA
Rennes, France
olivier.barais@irisa.fr

Figure: Software Language Engineering 2019

Bacatá: Notebooks for DSLs, Almost for Free

Mauricio Verano Merino[a,d], Jurgen Vinju[a,b], and Tijs van der Storm[b,c]

a Eindhoven University of Technology, The Netherlands
b Centrum Wiskunde & Informatica, The Netherlands
c University of Groningen, The Netherlands
d Océ Technologies B.V., The Netherlands

Figure: Art, Science, and Engineering of Programming 2020

Deriving REPL/Notebook – commonalities

- READ: Identify entry points, i.e. the alternatives in syntactic root
- EVAL: Connect entry points with evaluation function in DSL interpreter
- PRINT: Specify function to convert evaluation result to string
- LOOP:

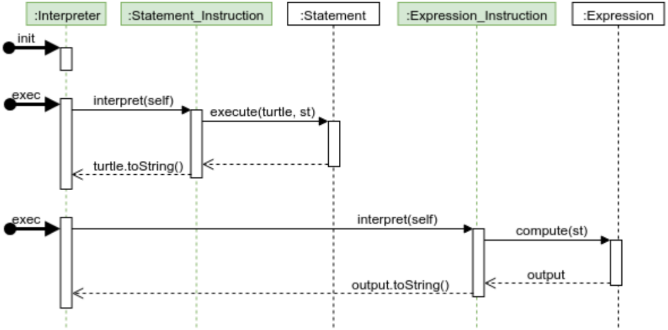


Figure 8. Overall Execution Flow for Logo

Deriving REPL/Notebook – commonalities

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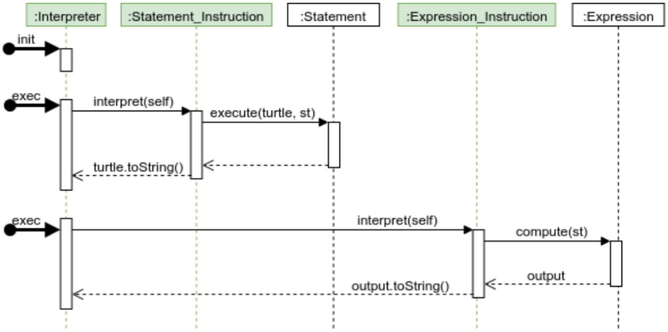

Figure 8. Overall Execution Flow for Logo

How does one execution affect the next?

Idea..!

Distinguish between REPL language and base language (e.g. JShell vs Java)

A Principled Approach to REPL Interpreters

L. Thomas van Binsbergen
Centrum Wiskunde & Informatica
Amsterdam, The Netherlands
ltvanbinsbergen@acm.org

Mauricio Verano Merino
Eindhoven University of Technology
Eindhoven, The Netherlands
m.verano.merino@tue.nl

Pierre Jeanjean
Inria, University of Rennes, CRNS,
IRISA
Rennes, France
pierre.jeanjean@inria.fr

Tijs van der Storm
Centrum Wiskunde & Informatica
Amsterdam, The Netherlands
University of Groningen
Groningen, The Netherlands
storm@cwi.nl

Benoit Combemale
University of Rennes, Inria, CNRS,
IRISA
Rennes, France
benoit.combemale@irit.fr

Olivier Barais
University of Rennes, Inria, CNRS,
IRISA
Rennes, France
olivier.barais@irisa.fr

Figure: Onward!2020

Observation..!

REPLs with incremental execution implement a language with the following property:

Observation..!

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A **sequential language** is a language in which $p_1 \otimes p_2$ is a (syntactically) valid program iff p_1 and p_2 are valid programs and iff $p_1 \otimes p_2$ is equivalent to 'doing' p_1 and then p_2

$$[\![p_1 \otimes p_2]\!] = [\![p_2]\!] \circ [\![p_1]\!]$$

Observation..!

REPLs with incremental execution implement a language with the following property:

A **sequential language** is a language in which $p_1 \otimes p_2$ is a (syntactically) valid program iff p_1 and p_2 are valid programs and iff $p_1 \otimes p_2$ is equivalent to 'doing' p_1 and then p_2

$$[\![p_1 \otimes p_2]\!] = [\![p_2]\!] \circ [\![p_1]\!]$$

A REPL is a monoid homomorphism between programs and their effects

REPLization in Onward!2020

Replization *is: extending a base language to a sequential variant*

REPLization in Onward!2020

Replization *is: extending a base language to a sequential variant*

1. Define the syntax of the extended language (**phrases**/**entry points**)

REPLization in Onward!2020

Replization *is: extending a base language to a sequential variant*

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2. Extend interpreter by linking phrases to functions in base interpreter

REPLization in Onward!2020

Replization *is: extending a base language to a sequential variant*

1. Define the syntax of the extended language (**phrases**/**entry points**)
2. Extend interpreter by linking phrases to functions in base interpreter
3. Add phrase composition operator to the language (it is now sequential by definition)

$$[\![p_1 \otimes p_2]\!] = [\![p_2]\!] \circ [\![p_1]\!]$$

REPLization in Onward!2020

Replization *is: extending a base language to a sequential variant*

1. Define the syntax of the extended language (**phrases**/**entry points**)
2. Extend interpreter by linking phrases to functions in base interpreter
3. Add phrase composition operator to the language (it is now sequential by definition)

$$[\![p_1 \otimes p_2]\!] = [\![p_2]\!] \circ [\![p_1]\!]$$

- The effect of one phrase on the next is determined by (2)

Onward!2020 (MiniJava case study)

```
Config eval((Phrase)`<Expression e> ;`, Config c)
  = catchExceptions(collectBindings(
      setOutput(createBinding(eval(c, e)))));

Config eval((Phrase)`<Statement s>`, Config c)
  = catchExceptions(collectBindings(
      setOutput(exec(s, c))));

Config eval((Phrase)`<ClassDecl cd>`, Config c)
  = catchExceptions(collectBindings(
      declareClass(cd, c)));

Config eval((Phrase)`<VarDecl vd>`, Config c)
  = catchExceptions(collectBindings(
      declareVariables(vd, c)));

Config eval((Phrase)`<MethodDecl md>`, Config c)
  = catchExceptions(collectBindings(
      declareGlobalMethod(md, c)));

Config eval((Phrase)`<Phrase p1> <Phrase p2>`, Config c)
  = eval(p2, eval(p1, c));
```

A Principled Approach to REPL Interpreters

L. Thomas van Binsbergen
Centrum Wiskunde & Informatica
Amsterdam, The Netherlands
ltvanbinsbergen@acm.org

Mauricio Verano Merino
Eindhoven University of Technology
Eindhoven, The Netherlands
m.verano.merino@tue.nl

Pierre Jeanjean
Inria, University of Rennes, CRNS, IRISA
Rennes, France
pierre.jeanjean@inria.fr

Tijs van der Storm
Centrum Wiskunde & Informatica
Amsterdam, The Netherlands
University of Groningen
Groningen, The Netherlands
storm@cwi.nl

Benoit Combemale
University of Rennes, Inria, CNRS, IRISA
Rennes, France
benoit.combemale@irit.fr

Olivier Barais
University of Rennes, Inria, CNRS, IRISA
Rennes, France
olivier.barais@irisa.fr

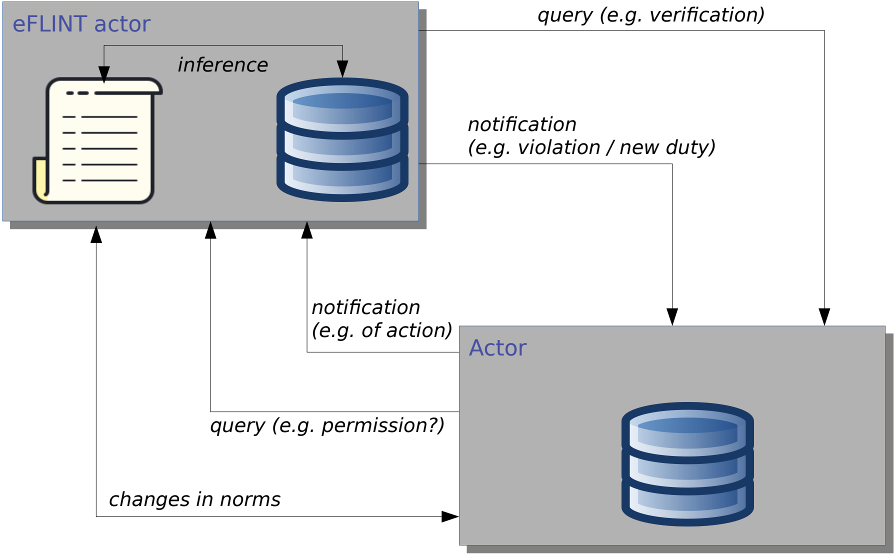
REPLization of eFLINT

1. eFLINT 2.0: REPLization applied to eFLINT using eFLINT 1.0 interpreter
   - valid **phrases**: type-declarations, initialization, triggering action/events, queries
   - enables backtracking for manual exploration
   - enables implementation of ‘eFLINT actors’
   - type-declarations as phrases enable dynamic policy construction

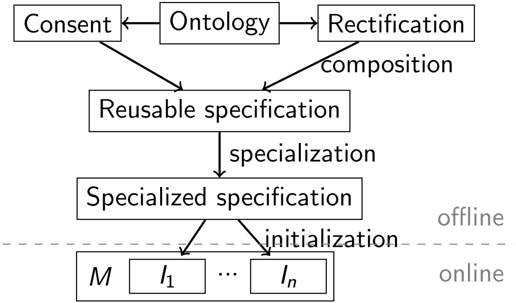
REPLization of eFLINT

1. eFLINT 2.0: REPLization applied to eFLINT using eFLINT 1.0 interpreter
   - valid **phrases**: type-declarations, initialization, triggering action/events, queries
   - enables backtracking for manual exploration
   - enables implementation of ‘eFLINT actors’
   - type-declarations as phrases enable dynamic policy construction
2. Tools based on the same REPLized interpreter
   - `eflint-repl`: command line tool for manual exploration and debugging
   - `eflint-server`: server that listens on a port for incoming phrases

eFLINT actors



eFLINT integration – overview (GDPR example)



eFLINT integration – example

Reusable GDPR concepts

```
Fact controller
Fact subject

Fact data
Fact subject-of
 Identified by subject * data
```

Specialisation to application

```
Fact bank   //exactly one
Fact client //exactly one

Fact controller
 Derived from bank
Fact subject
 Derived from client

Fact data
 Identified by Int

Event data-change
 Terminates data
 Creates data(data + 1)

Fact subject-of
 Derived from
  subject-of(client,processed)
 ,subject-of(client,data)

Fact processed
 ...
```

Instantiation at run-time

```
+bank(GNB).
+client(Alice).
+data(0).
```

Derived after instantiation

```
+controller(GNB).
+subject(Alice).
+subject-of(Alice,0).
```

Modular GDPR specification

Dynamic generation of access control policies from social policies

L. Thomas van Binsbergen[1,a], Milen G. Kebede[a], Joshua Baugh[b], Tom van Engers[a], Dannis G. van Vuurden[b]

[a] *Informatics Institute, University of Amsterdam, 1090GH Amsterdam, The Netherlands*
[b] *Princess Maxima Center for Pediatric Oncology, Department of Neuro-oncology, Utrecht, The Netherlands*

Figure: ICTH2021

```
Act collect-personal-data
  Actor controller
  Recipient subject
  Related to data, processor, purpose
    Where subject-of(subject, data)
  Creates processes(processor, data, controller, purpose)
```

Article 5 – processing conditions

Article 5

Principles relating to processing of personal data

1. Personal data shall be:

(a) processed lawfully, fairly and in a transparent manner in relation to the data subject ('lawfulness, fairness and transparency');

(b) collected for specified, explicit and legitimate purposes and not further processed in a manner that is incompatible with those purposes; further processing for archiving purposes in the public interest, scientific or historical research purposes or statistical purposes shall, in accordance with Article 89(1), not be considered to be incompatible with the initial purposes ('purpose limitation');

(c) adequate, relevant and limited to what is necessary in relation to the purposes for which they are processed ('data minimisation');

(d) accurate and, where necessary, kept up to date; every reasonable step must be taken to ensure that personal data that are inaccurate, having regard to the purposes for which they are processed, are erased or rectified without delay ('accuracy');

```
Fact minimal-for-purpose Identified by processes
Extend Act collect-personal-data Conditioned by minimal-for-purpose(data, purpose)
```

Listing 4: Member (1c)

```
Fact accurate-for-purpose Identified by data * purpose
Extend Act collect-personal-data Conditioned by accurate-for-purpose(data, purpose)
```

Listing 5: Member (1d)

Article 6 – legal processing

Article 6

Lawfulness of processing

1. Processing shall be lawful only if and to the extent that at least one of the following applies:

(a) the data subject has given consent to the processing of his or her personal data for one or more specific purposes;

(b) processing is necessary for the performance of a contract to which the data subject is party or in order to take steps at the request of the data subject prior to entering into a contract;

(c) processing is necessary for compliance with a legal obligation to which the controller is subject;

```
Fact consent Identified by subject * controller * purpose * data
Extend Act collect-personal-data
  Holds when consent(subject, controller, purpose, data)
```

Listing 6: Member (1a)

```
Fact has-legal-obligation Identified by processes
Extend Act collect-personal-data
  Holds when has-legal-obligation(controller, purpose)
```

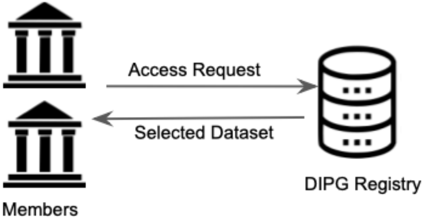
Listing 7: Member (1c)

Compliance questions

According to the GDPR and the DIPG regulatory document:

1. What conditions need to be fulfilled by a member before making data available?

2. What conditions need to be fulfilled when accessing data from the registry?



Compliance Question 1

DIPG Regulatory document – Article 4(2):

Members should transfer data to the DIPG registry in a coded form only

```
Fact coded Identified by dataset

Act make-data-available
  Actor institution
  Recipient dcog
  Related to dataset
  Conditioned by coded(dataset)
  Holds when member(institution)
```

Compliance Question 1

```
Extend Act make-data-available Syncs with (Foreach donor:
  collect-personal-data(controller = institution
                       ,subject    = donor
                       ,data       = dataset
                       ,processor  = "DCOG"
                       ,purpose    = "DIPGResearch")
    When subject-of(donor, dataset))
```

An institution can make a dataset available when (for each donor (subject) in the dataset):

- The institution is a member (DIPG Regulatory Document – Article 4(2))
- Data is coded (DIPG Regulatory Document – Article 4(2))
- Consent is given by the donor for the processing of their personal data by the DCOG for the purpose of DIPGResearch (GDPR – Article 6)
- Data should be accurate for the purpose DIPGResearch (GDPR – Article 5)

Subsection 3

Goals for eFLINT 3.0

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Language design

- Clear separation between:
  - Computational concepts: actions, events, synchronisation
  - Normative concepts: prohibition, obligation, permission, power
- A module system, introducing namespaces and a versioning mechanism
- Modular, rule-based specification as the default through implicit extensions
- (eFLINT 2.0 can serve as a core/inner language to eFLINT 3.0)

Language engineering

- Additional static analyses to detect inconsistencies and possible errors
- Detailed reports as part of reasoning output to improve explainability
- User-friendly programming environment for writing and testing specifications
- Interoperability, e.g. with linked data / semantic web

Section 3

Reflections

Bounded vs open-ended domains

Static analyses

- eFLINT 1.0 enabled automated scenarios assessment in finite domain
- Future work: applying model checking, and/or property-based testing

Dynamic enforcement

- eFLINT 2.0 enabled dynamic interpretation, qualification and assessment
- Domain established at runtime, based on the contents of the knowledge base

Design decision:

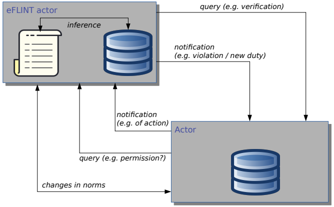
When enumerating instances, first check domain of type, then knowledge base

```
// opt1: Fact person Identified by Alice, Bob, Chloe, David
// opt2: +person(Alice). +person(Bob). +person(Chloe). +person(David).

?(Forall person: !homework-due(person))
```

Two approaches to enforcing social policies

Embedding eFLINT specifications as eFLINT actors, akin to 'policy decision point':



Generating system-level policies, akin to 'policy administration point'

Dynamic generation of access control policies from social policies

L. Thomas van Binsbergen[1,a], Milen G. Kebede[a], Joshua Baugh[b], Tom van Engers[a], Dannis G. van Vuurden[b]

[a] *Informatics Institute, University of Amsterdam, 1090GH Amsterdam, The Netherlands*
[b] *Princess Maxima Center for Pediatric Oncology, Department of Neuro-oncology, Utrecht, The Netherlands*

Takeaway messages

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At the Complex Cyber Infrastructure group, we are experimenting with approaches to enforcing laws, regulations, agreements and contracts in (distributed) systems

The eFLINT DSL serves as a tool to demonstrate and experiment with various aspects of our approach, with a focus on runtime enforcement using 'regulatory services'

These experiments highlight the importance of software engineering concepts such as modularity, reuse, version control, overriding mechanisms and inheritance

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At the Complex Cyber Infrastructure group, we are experimenting with approaches to enforcing laws, regulations, agreements and contracts in (distributed) systems

The eFLINT DSL serves as a tool to demonstrate and experiment with various aspects of our approach, with a focus on runtime enforcement using 'regulatory services'

These experiments highlight the importance of software engineering concepts such as modularity, reuse, version control, overriding mechanisms and inheritance

The next phase is to improve the practicality and usability of eFLINT and to demonstrate our approach in data exchange systems such as the Amsterdam Data Exchange (AMdEX)

Towards a DSL for formalising laws and regulations

intermediate findings and results

L. Thomas van Binsbergen

Informatics Institute, University of Amsterdam
ltvanbinsbergen@acm.org

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Strumenta, Virtual Meetup

UNIVERSITY OF AMSTERDAM