Domain-specific languages, regulated systems and sustainability

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September 25, 2023

Section 1

Software languages and sustainability

Sustainability challenges in software

In what ways is sustainability promoted by **domain-specific languages**, **formal semantics** *and their application in* **regulated systems**?

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Technological and social challenges:

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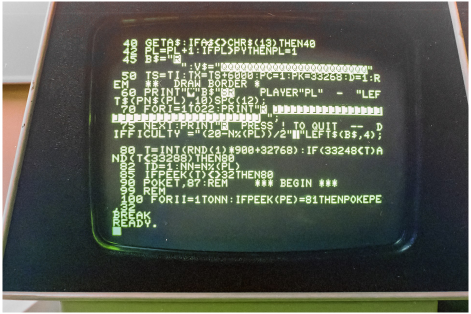
- The ability of software to adjust to changing circumstances, e.g. new execution environments (such as platforms, devices, services), new and updated regulations, and changing teams of developers/maintainers
- The continued ability to leverage the creative value put into software, i.e. can we still understand the logic of the code / the algorithm? can we extract and reuse it?

Legacy Systems

- Written in arcane, unstructured languages,
- hard to maintain and costly to migrate
- grew organically, in a non-modular fashion,
- uses non-standardised interfaces between components and other software,
- has little documentation or of poor quality,
- may require specific environments to run,
- and no one ‘owns’ the software anymore, nor understands how it does what it does



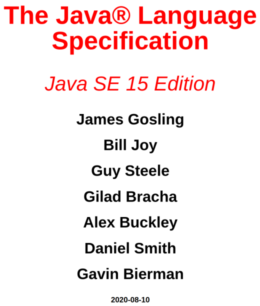
```
 40 GETA$:IFA$<>CHR$(13)THEN40
 42 PL=PL+1:IFPL>PYTHENPL=1
 45 B$="R
       ":V$="QQQQQQQQQQQQQQQQQQQQQQQQQQ"
 50 TS=TI:TX=TS+6000:PC=1:PK=33268:D=1:R
EM   **   DRAW BORDER *
 60 PRINT"▙"B$"SR     PLAYER"PL"  -  "LEF
T$(PN$(PL),10)SPC(12);
 70 FORI=1TO22:PRINT"R ▟▟▟▟▟▟▟▟▟▟▟▟▟▟▟▟▟▟▟
▟▟▟▟▟▟▟▟▟▟▟▟▟▟▟▟▟▟▟▟▟ ";
 75 NEXT:PRINT"R  PRESS ! TO QUIT  --  D
IFFICULTY ="(20-N%(PL))/2"█"LEFT$(B$,4);

 80 T=INT(RND(1)*900+32768):IF(33248<T)A
ND(T<33288)THEN80
 82 TD=1:NN=N%(PL)
 85 IFPEEK(T)<>32THEN80
 90 POKET,87:REM     *** BEGIN ***
 99 REM
 100 FORII=1TONN:IFPEEK(PE)=81THENPOKEPE
,32
BREAK
READY.
█
```

BASIC program on an old Commodore

Formal semantics

Unlike natural languages, software languages are potentially **formal** *and* **exact**
However, few languages have a 'formal contract' between design and implementation

Formal semantics enables such formal contracts

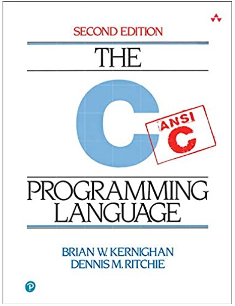


The Java® Language Specification

Java SE 15 Edition

James Gosling
Bill Joy
Guy Steele
Gilad Bracha
Alex Buckley
Daniel Smith
Gavin Bierman

2020-08-10

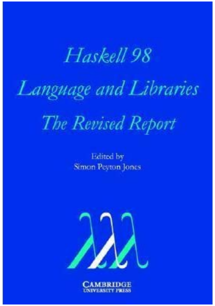


SECOND EDITION

THE C PROGRAMMING LANGUAGE

ANSI C

BRIAN W. KERNIGHAN
DENNIS M. RITCHIE



Haskell 98
Language and Libraries
The Revised Report

Edited by
Simon Peyton Jones

CAMBRIDGE
UNIVERSITY PRESS

Reference manuals typically have formal syntax and informal semantics

Domain-specific languages

Formalisations of general-purpose languages are complex and hard to maintain

Domain-specific languages have much smaller scopes

Figure: MySQL

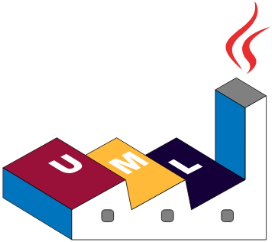


Figure: PlantUML

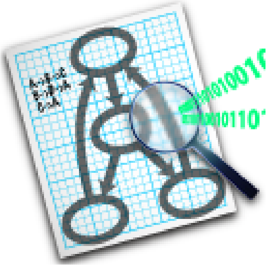


Figure: DOT

Model-driven engineering

Generate implementations from *models* of the desired system:

- Specify the essence, abstracting away from implementation details
- Visualisation, inspection, and checking of model in isolation

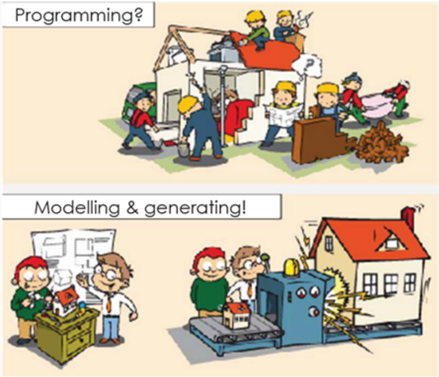


Figure: by Johan den Haan, CTO at Mendix

Formal semantics – The PLanCompS project

Engineers typically learn individual languages by ‘speaking’ with a compiler

Programming should be taught in terms of paradigm-agnostic concepts

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The PLanCompS project: `http://plancomps.org`

Component-based approach towards formal, operational semantics

Main contributions of the project:

- A library of highly reusable, executable *fun*damental *con*structs (*funcons*)[a]
- The meta-language CBS for defining component-based semantics[b]

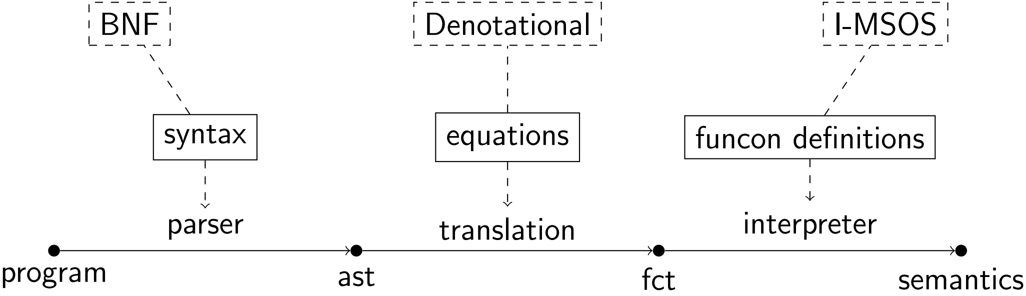
ROYAL HOLLOWAY UNIVERSITY OF LONDON

Swansea University Prifysgol Abertawe

[a] `https://plancomps.github.io/CBS-beta/Funcons-beta/Funcons-Index/`

[b] *Executable Component-Based Semantics*. Van Binsbergen, Sculthorpe, Mosses. JLAMP 2019

Applying the PLanCompS approach



Can this pipeline support modular, incremental DSL development?

Can funcons serve as the basis for teaching programming?

What is the state of the funcon library?

Verified and available at `https://plancomps.github.io/CBS-beta/`

- Procedural: procedures, references, scoping, iteration
- Functional: functions, bindings, datatypes, pattern matching
- Object-oriented: objects, classes, inheritance
- Abnormal control: exceptions, break/continue, delimited continuations

Unverified as of yet (prototype phase)

- Concurrency: multi-threading
- Logical programming: backtracking, unification
- Meta-programming: AST conversions, staged evaluation[1]

[2] *Funcons for Homogeneous Generative Meta-Programming*. Van Binsbergen. GPCE 2018

$$\mathsf{strict}[\![E1 \text{ '\&\&' } E2]\!] = \mathbf{and}(\mathsf{strict}[\![E1]\!], \mathsf{strict}[\![E2]\!])$$

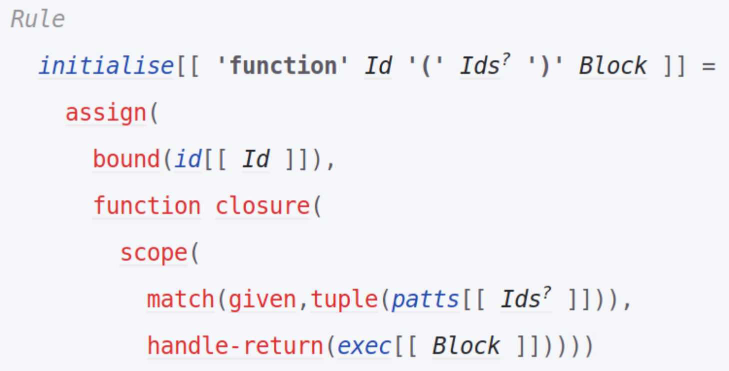
$$\ldots = \ldots$$

$$\text{strict}\llbracket E1\ \text{'\&\&'}\ E2\rrbracket = \textbf{and}(\text{strict}\llbracket E1\rrbracket, \text{strict}\llbracket E2\rrbracket)$$

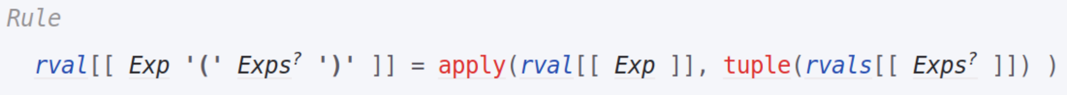
$$\ldots = \ldots$$

$$\text{non-strict}\llbracket E1\ \text{'\&\&'}\ E2\rrbracket = \textbf{if-else}(\text{non-strict}\llbracket E1\rrbracket, \text{non-strict}\llbracket E2\rrbracket, \textbf{false})$$

$$\ldots = \ldots$$

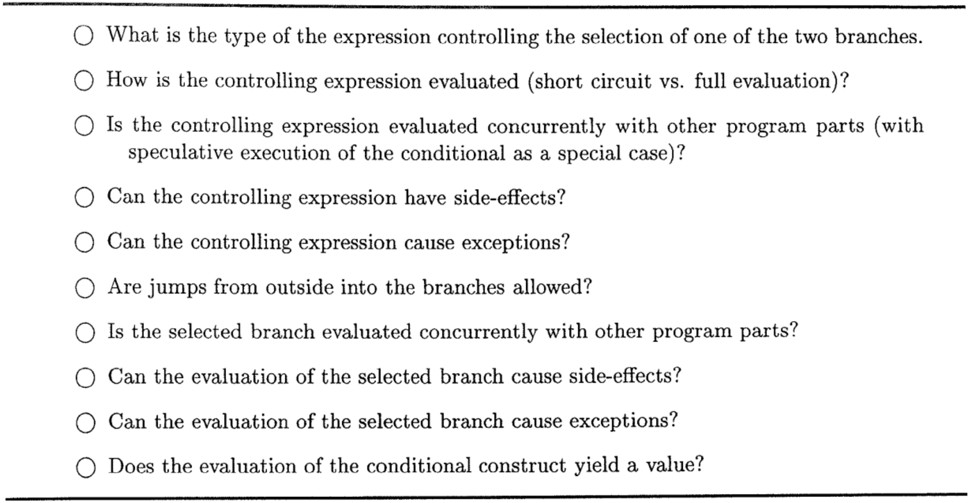


```
Rule
  initialise[[ 'function' Id '(' Ids? ')' Block ]] =
    assign(
      bound(id[[ Id ]]),
      function closure(
        scope(
          match(given,tuple(patts[[ Ids? ]])),
          handle-return(exec[[ Block ]]))))
```



```
Rule
  rval[[ Exp '(' Exps? ')' ]] = apply(rval[[ Exp ]], tuple(rvals[[ Exps? ]]) )
```

What are the right abstractions to be captured by the funcons?



○ What is the type of the expression controlling the selection of one of the two branches.

○ How is the controlling expression evaluated (short circuit vs. full evaluation)?

○ Is the controlling expression evaluated concurrently with other program parts (with speculative execution of the conditional as a special case)?

○ Can the controlling expression have side-effects?

○ Can the controlling expression cause exceptions?

○ Are jumps from outside into the branches allowed?

○ Is the selected branch evaluated concurrently with other program parts?

○ Can the evaluation of the selected branch cause side-effects?

○ Can the evaluation of the selected branch cause exceptions?

○ Does the evaluation of the conditional construct yield a value?

Table 5: Some of the possible parameters of a generic conditional construct.

[3] *Semantics of Programming Languages: A Tool-Oriented Approach*. J. Heering, P. Klint. SIGPLAN Not. 2000

Funcon $\textbf{if-else}(\_ : \textbf{booleans}, \_ : \Rightarrow T, \_ : \Rightarrow T) : \Rightarrow T$

$$\textit{Funcon}\ \textbf{if-else}(\_ : \textbf{booleans}, \_ : \Rightarrow T, \_ : \Rightarrow T) : \Rightarrow T$$

What is the type of the controlling expression? for example: integer values

$$\text{eval}[\![E1\ \text{'?'}\ \ E2\ \text{':'}\ \ E3]\!] = \textbf{if-else}(\textbf{is-greater}(\text{strict}[\![E1]\!], 0), \text{strict}[\![E2]\!], \text{strict}[\![E3]\!])$$

$$\ldots = \ldots$$

$$\textit{Funcon}\ \textbf{if-else}(\_ : \textbf{booleans}, \_ : \Rightarrow T, \_ : \Rightarrow T) : \Rightarrow T$$

How is the controlling expression evaluated? for example: short-circuit

$$\text{eval}[\![E1\ \text{'?'}\ \ E2\ \text{':'}\ \ E3]\!] = \textbf{if-else}(\text{non-strict}[\![E1]\!], \text{non-strict}[\![E2]\!], \text{non-strict}[\![E3]\!])$$

$$\ldots = \ldots$$

$$\textit{Funcon}\ \textbf{if-else}(\_ : \textbf{booleans}, \_ : \Rightarrow T, \_ : \Rightarrow T) : \Rightarrow T$$

Does the evaluation of the conditional yield a value? for example: no

$$\text{eval}[\![E1\ \text{'?'}\ \ E2\ \text{':'}\ \ E3]\!] = \textbf{effect}(\textbf{if-else}(\text{strict}[\![E1]\!], \text{strict}[\![E2]\!], \text{strict}[\![E3]\!]))$$

$$\ldots = \ldots$$

Funcons also have informal semantics (no need to always worry about the details!)

I-MSOS funcon definitions serve as a reference for discussions, implementations

Reflections on sustainability

The continued ability to leverage the creative value put into software, i.e. can we still understand the logic of the code / the algorithm? can we extract and reuse it?

- Formal languages are technology-independent (maths/funcons as a lingua franca)
- Language design based on sound principles, fundamental programming concepts and insights from human-computer interaction

Section 2

Regulated systems

Regulated data exchange:

Data exchange systems governed by regulations, agreements and policies

as an instance of

Regulated systems:

software systems with embedded regulatory services derived from norm specifications that monitor and/or enforce compliance

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NWO-funded: SSPDDP – Secure and scalable, policy-driven data exchange

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Regulated systems:

software systems with embedded regulatory services derived from norm specifications that monitor and/or enforce compliance

NWO-funded: SSPDDP – Secure and scalable, policy-driven data exchange

EFRO-funded: AMDEX Fieldlab – neutral data-exchange infrastructure

Towards regulated systems

Monolithic programs

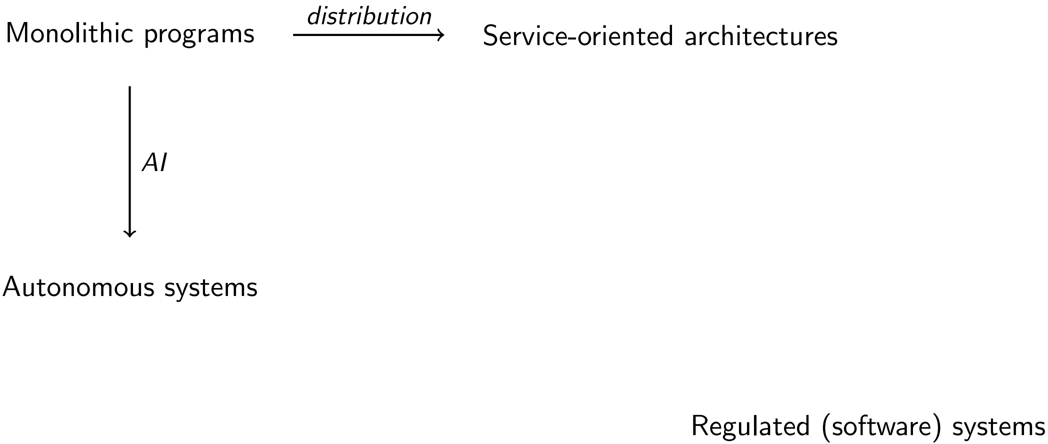
Regulated (software) systems

Towards regulated systems

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

Regulated (software) systems

Towards regulated systems



Monolithic programs

distribution

Service-oriented architectures

AI

Autonomous systems

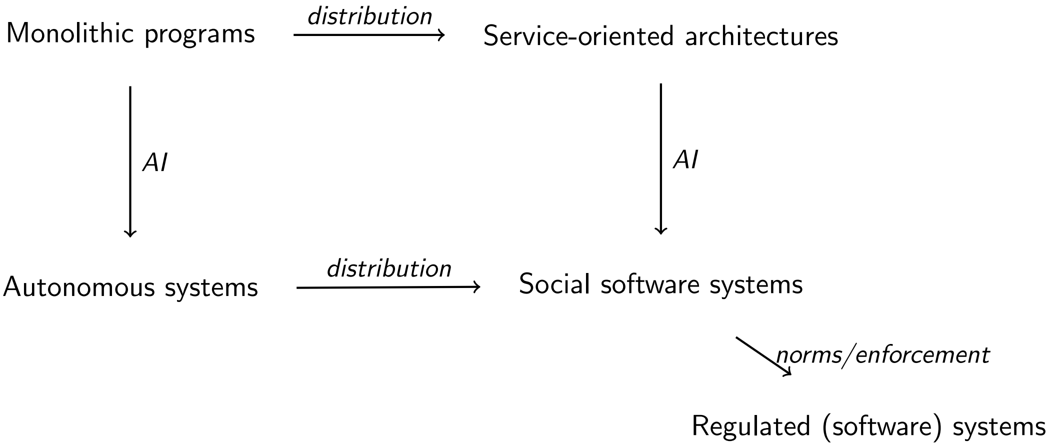
Regulated (software) systems

Towards regulated systems

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

Regulated (software) systems

Towards regulated systems



Monolithic programs

distribution

Service-oriented architectures

AI

AI

Autonomous systems

distribution

Social software systems

norms/enforcement

Regulated (software) systems

Regulated systems – points to address

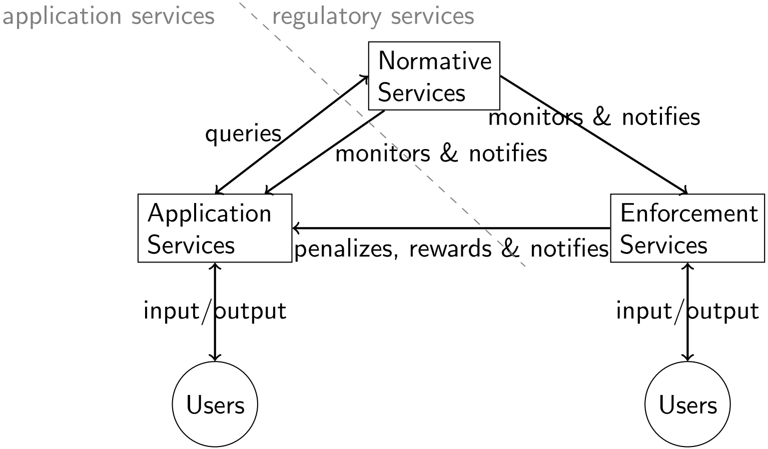
Formalization of applicable norms: reusable, modular and dynamically updateable

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, scheduling
- Dynamic ex-ante: apply rules at run-time, guaranteeing compliance
  permits decisions (behavioural, normative) that depend on input
- Embedded ex-post enforcement: specified responses to violations
  admits (regulated) non-compliant behaviour, e.g. based on risk assessment by agent
- External ex-post enforcement: external responses to violations
  e.g. auditing, conformance checking
  permits (human-)intervention in running system

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

Our approach to regulated systems



Regulated *systems* – points to address

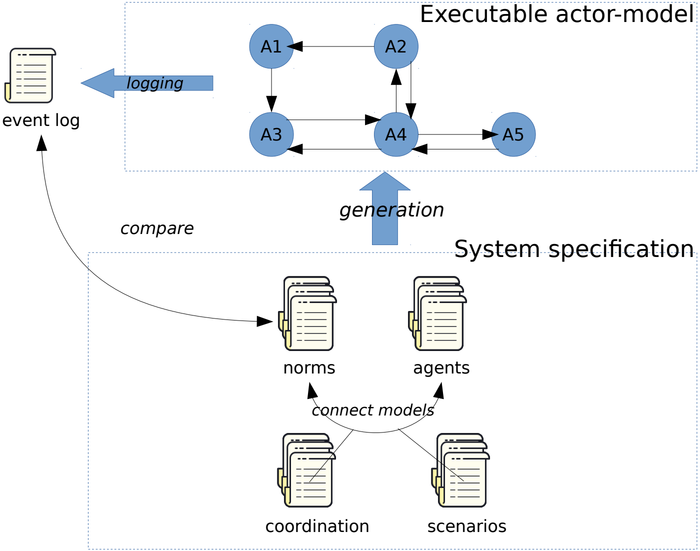
Derivation of regulatory services from formalization of norms

Interfacing between application and regulatory services:

- Monitoring (communicated and silent) behaviour 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 and 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

Our approach to model-driven experimentation



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

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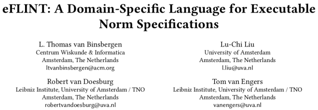

eFLINT: A Domain-Specific Language for Executable Norm Specifications

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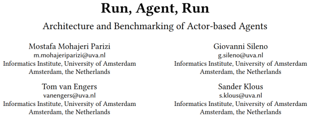

Run, Agent, Run

Architecture and Benchmarking of Actor-based Agents

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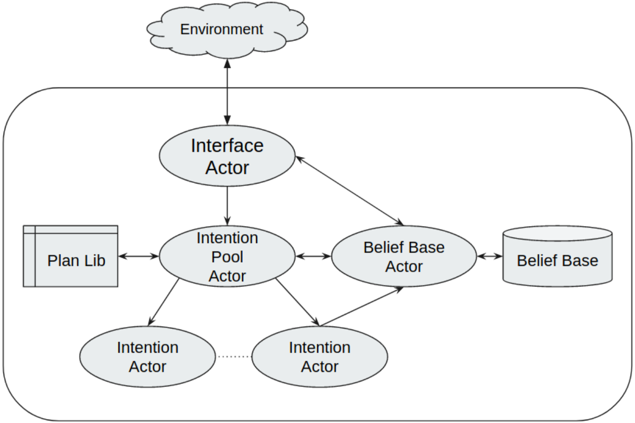
published @ SPLASH 2020

AgentScriptCC

Agents are translated into actor-based micro-systems

Consisting of:

- Interface actor
- Intention pool actor
- $n \geq 1$ Intention actors
- Belief base actor
- Belief base
- Plan library



The KYC case study – SSPDDP

Case study around the Know Your Customer principle adopted by financial institutions to meet international regulations by assessing client profiles to compute risk

Involves three types of “normative documents”:

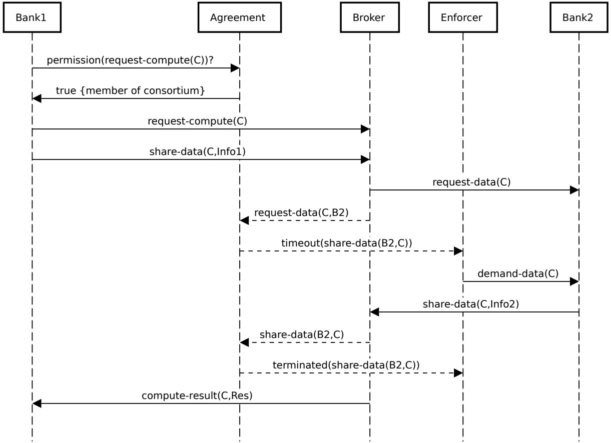
1. Sharing agreement – a contract between banks of a consortium
2. Internal policy – a sort of contract between bank and employee
3. GDPR – a sort of contract between bank and client

For each document we can *separately* describe its norms, the behaviour of relevant actors (clients, banks, employees and broker) and how the norms are enforced

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



eFLINT example – GDPR

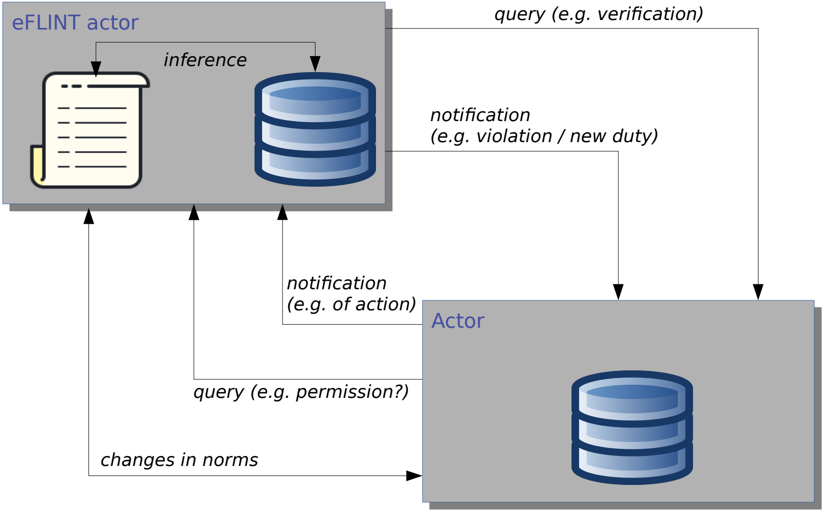
(Article 16) The data subject shall have the right to obtain from the controller without undue delay the rectification of inaccurate personal data concerning him or her. [...]

```
Act demand-rectification
 Actor subject
 Recipient controller
 Related to purpose
 Creates rectification-duty()
 Holds when (Exists data, processor:
  subject-of() && processes() && !accurate-for-purpose())

Duty rectification-duty
  Holder controller
  Claimant subject
  Related to purpose
  Violated when undue-rectification-delay()

Fact undue-rectification-delay
  Identified by controller * purpose * subject
```

eFLINT actors



From eFLINT specifications to eFLINT actors

idea: let ‘eFLINT actors’ administer eFLINT specifications

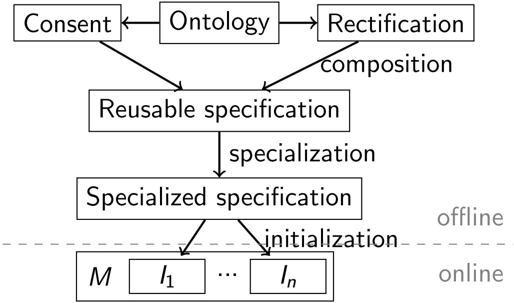
Incoming messages trigger input events

- Creating/terminating facts and triggering actions and events (statements)
  - Dynamic scenario (case) construction with automated assessment
- Creating, modifying or removing fact-, act-, event- and duty-types (declarations)
  - Dynamic policy construction
- Queries, e.g. to check whether actions are permitted or duties are violated

Output events trigger outgoing messages

- Notifications of newly permitted actions
- Notifications of executed actions and whether they were permitted
- Notifications of new duties and violations of duties
- Querying an actor to determine or verify the truth of a fact

eFLINT integration and reuse – overview



eFLINT integration – example

Reusable GDPR concepts

```
Fact controller
Fact subject

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

Specialization to application

```
Fact bank
Fact client

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
 ...
```

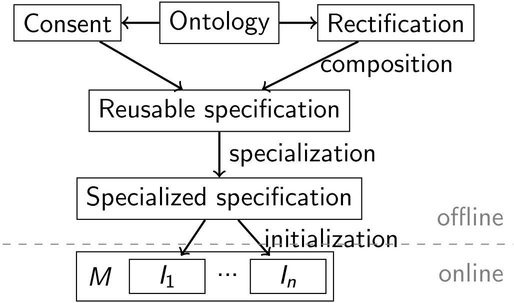
Instantiation at run-time

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

Derived after instantiation

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

eFLINT integration – overview



Monitoring GDPR compliance

```
WHEN
  Message(client:ClientRef,bank:BankRef,req:BankTypes.ApplicationRequest)
TRIGGER
  INIT gdpr(bank, client)                          // instantiates GDPR actor

INIT gdpr                                          // defines constructor
  WITH bank:BankRef, client:ClientRef              // Scala class parameters
  IDENTIFIED BY (bank.path.name, client.path.name) // pair of values as id
  FROM "gdpr_specialization.eflint"                // eFLINT file to load
TRIGGER                                            // eFLINT initialization
  +client(${client.path.name}).                    //        statements
  +bank(${bank.path.name}).
  +data(0).

WHEN
  Message(client:ClientRef,bank:BankRef,msg:BankTypes.CountryUpdate)
TRIGGER IN gdpr(bank.path.name, client.path.name)
  demand-rectification(purpose=KYC).               // qualified as demand
```

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declarative reasoning about facts, actions and duties

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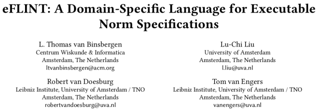

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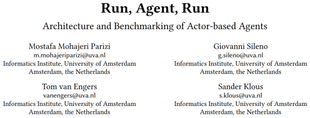

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AgentScriptCC DSL

Main component: ‘plan rules’ `E : C => A`

- when *event* `E` happens
- and if *condition* `C` holds,
- then do *action* `A`

Example from **client**:

- `E`: Agent receives the message `give_info`
- `C`: `B` is a bank to which client is applying or has successfully applied, `S` is SBI-code of client, `C` is country where client is based and message sender is employee of bank B.
- `A`: send SBI-code and country to original sender of `give_info` message

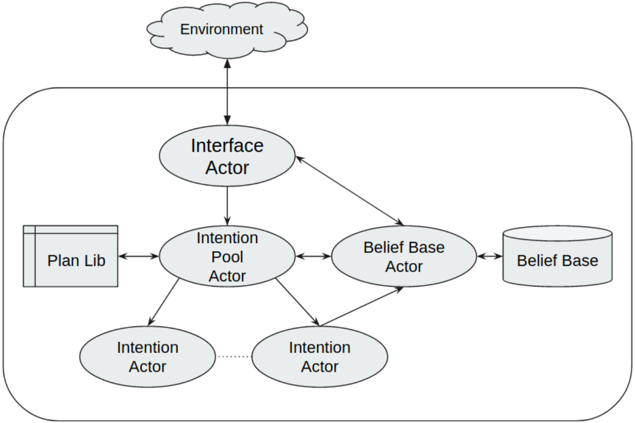
```
+!give_info(B) :
 my_sbi(S) &&
 my_country(C) &&
 employee_of(#executionContext.sender.name, B) &&
 (applying_to(B) || client_of(B)) =>
  #achieve(#executionContext.sender.ref,info(S,C)).
```

AgentScriptCC

Agents are translated into actor-based micro-systems

Consisting of:

- Interface actor
- Intention pool actor
- $n \geq 1$ Intention actors
- Belief base actor
- Belief base
- Plan library



AgentScriptCC - Internal policy example

(Rule 1) An employee has the duty to perform a risk analysis on the profile of a client within four weeks of the creation or modification of the profile

Employee

```
+!interview(Client) :
 bank(B) &&
 B == #executionContext.sender.name =>
  #achieve(Client,give_info(B)).

+!info(SBI,Country) :
 bank(B) =>
  Client = #executionContext.sender.name;
  Info = info(SBI,Country);
  +information(Client,Info);
  #achieve(B,interview_complete(Client,Info)).

+!do_risk_analysis(C,info(SBI,Country)) =>
  B = #executionContext.sender.name;
  R = #kyc.algorithms.risk(B,SBI,Country);
  #achieve(B,assign_risk(C,R)).
```

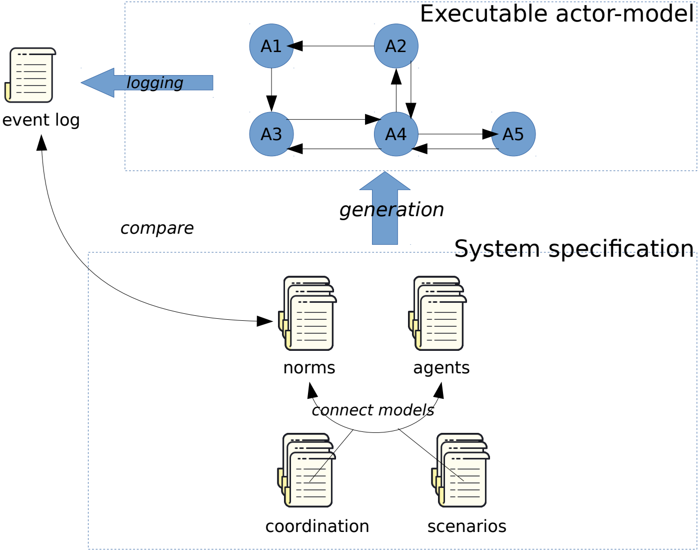
Client

```
+!give_info(B) :
 my_sbi(S) &&
 my_country(C) &&
 employee_of(#executionContext.sender.name, B) &&
 (applying_to(B) || client_of(B)) =>
  #achieve(#executionContext.sender.ref,info(S,C)).
```

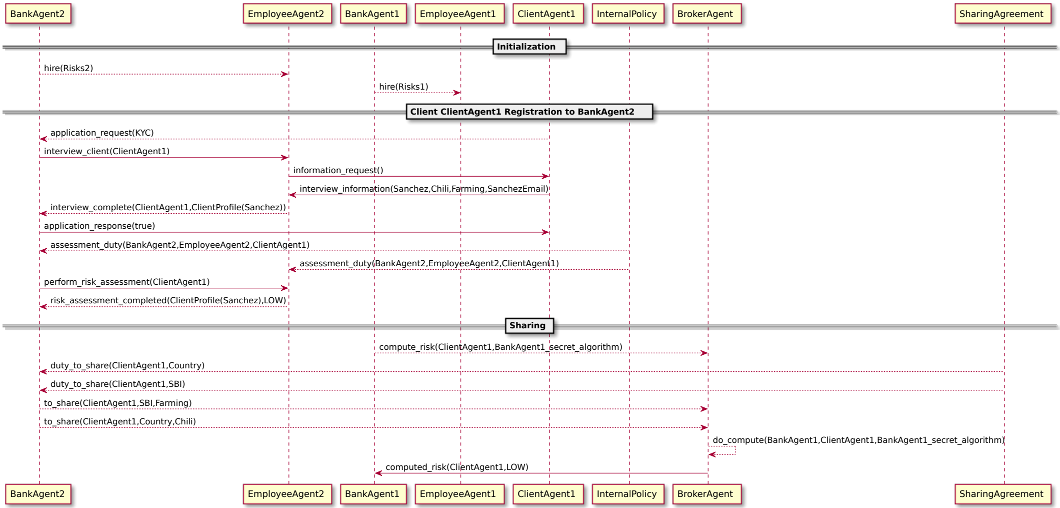
Bank

```
+!interview_complete(Client,Info):
 E = #executionContext.sender.name &&
 employee(E) &&
 not client(Client) =>
  #println("interview done for " + Client);
  +information(Client,Info);
  +client(Client);
  #achieve(E,do_risk_analysis(Client,Info)).
```

Our approach to model-driven experimentation



Example scenario execution



BankAgent2 EmployeeAgent2 BankAgent1 EmployeeAgent1 ClientAgent1 InternalPolicy BrokerAgent SharingAgreement

Initialization

hire(Risks2)

hire(Risks1)

Client ClientAgent1 Registration to BankAgent2

application_request(KYC)

interview_client(ClientAgent1)

information_request()

interview_information(Sanchez,Chili,Farming,SanchezEmail)

interview_complete(ClientAgent1,ClientProfile(Sanchez))

application_response(true)

assessment_duty(BankAgent2,EmployeeAgent2,ClientAgent1)

assessment_duty(BankAgent2,EmployeeAgent2,ClientAgent1)

perform_risk_assessment(ClientAgent1)

risk_assessment_completed(ClientProfile(Sanchez),LOW)

Sharing

compute_risk(ClientAgent1,BankAgent1_secret_algorithm)

duty_to_share(ClientAgent1,Country)

duty_to_share(ClientAgent1,SBI)

to_share(ClientAgent1,SBI,Farming)

to_share(ClientAgent1,Country,Chili)

do_compute(BankAgent1,ClientAgent1,BankAgent1_secret_algorithm)

computed_risk(ClientAgent1,LOW)

BankAgent2 EmployeeAgent2 BankAgent1 EmployeeAgent1 ClientAgent1 InternalPolicy BrokerAgent SharingAgreement

Conclusions

- We can produce executable models of regulated systems, by combining
  - normative actors derived from normative specifications (in eFLINT),
  - actor implementations derived from agent scripts (in AgentScriptCC),
  - queries sent to normative actors for dynamic ex-ante enforcement, and
  - enforcement actors for dynamic ex-post enforcement
- enabling experiments with norms, enforcement mechanisms and system set-ups.

Takeaways

The complex-cyber infrastructure group of the University of Amsterdam is experimenting with **regulated sytems** *– in which norms from a variety of sources are enforced – by deriving* **executable models** *from* **high-level specifications**

Such systems require **several kinds of enforcement mechanisms** *for norms, based on whether compliance can/should be/is checked before or after a violation occurs and before or after an application runs*

Reflections on sustainability

The continued ability to leverage software through its execution, i.e. ensuring there are practical means of running a software product:

- Model-driven engineering simplifies adopting new execution platforms

Reflections on sustainability

The ability of software to adjust to changing circumstances, e.g. new execution environments (such as platforms, devices, services), new and updated regulations, and changing teams of developers/maintainers

- Standardisation and service-oriented architectures increase flexibility
- Regulatory services derived from independent, explicit formalisations of norms make it possible to adjust to changes in regulations

Reflections on sustainability

The continued ability to leverage the creative value put into software, i.e. can we still understand the logic of the code / the algorithm? can we extract and reuse it?

- Formal languages are technology-independent (maths/funcons as a lingua franca)
- Language design based on sound principles, fundamental programming concepts and insights from human-computer interaction

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Domain-specific languages, regulated systems and sustainability

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