A Language Stack for implementing Contracts

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Context

SMART CONTRACT

An actual contract, executed automatically.

over time

Any

Turing Complete

Program running on a Blockchain.

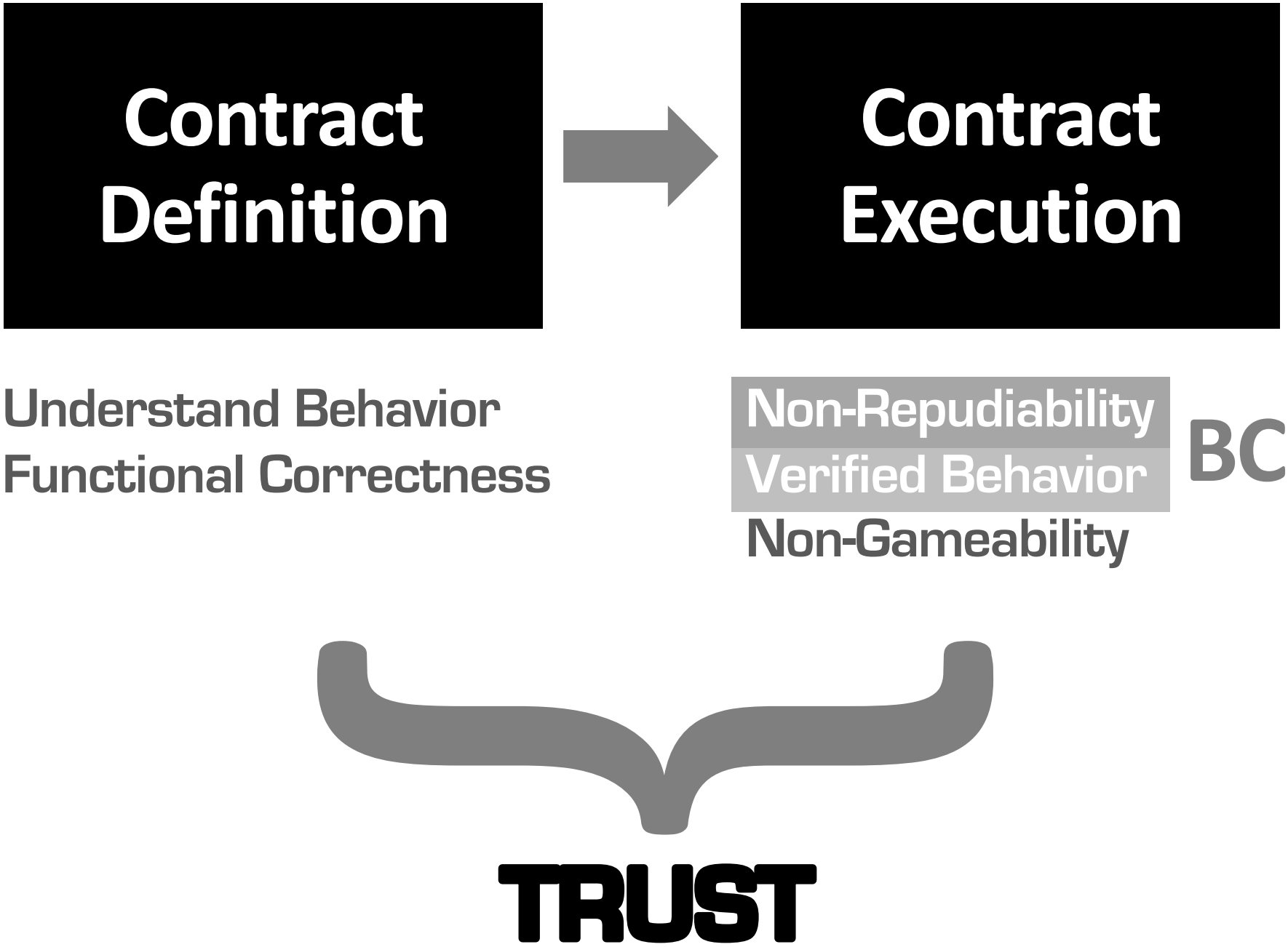
An actual contract, executed automatically.

Multiple Parties.
Decision ||
Agreement ||
Coordination.
(Legally) Binding &
Trusted.

Formal Language.
Checkable.
Understandable.
„Event Tracking“
Progress over time

Contract Definition

Contract Execution


Contract Definition
Contract Execution
Understand Behavior
Functional Correctness
Non-Repudiability
Verified Behavior
Non-Gameability
BC
TRUST

Blockchains
can provide certain
non-functional properties
to executable contracts.

Blockchains
are a suitable (partial)
implementation technology
iff these properties are needed.

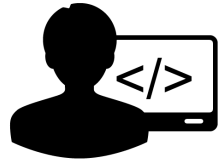
Verification

Ensure that the program performs correctly the things the program text tells it to do.

Validation

Ensure that the program does the correct things, wrt. to the requirements.

Verification



Contract Execution

Ensure that the program performs correctly the things the program text tells it to do.

Validation

Contract Definition

Ensure that the program does the correct things, wrt. to the requirements.

Correct-by-Construction

The language/framework/ API/modeling tool doesn't allow a particular class of mistakes.

Analysis-and-Fix

You analyze the code/model after the fact and try to find problems which devs then fix.

Correct-by-Construction

Languages

Analysis-and-Fix

Analysis Tools

Formal Language.
Checkable.
Understandable.

DSL

Domain Specific Language

Languages

Analysis Tools

Languages

Analysis Tools

State machines can **always** be checked for dead states and unused transitions.

Decision tables must **always** be overlap-free and complete.

Lots of History & Research

Computational Law

Obligation, Permission
Ordering, Causality, Time
Event, State

Lots of History & Research

Composing contracts: an adventure in financial engineering

https://lexifi.com/files/resources/MLFiPaper.pdf

POETS Process-oriented event-driven transaction systems

https://github.com/legalese/poets/blob/master/doc/Henglein%20-%20POETS%20Process-oriented%20event-driven%20transaction%20systems.pdf

Contracts in Programming and in Enterprise Systems

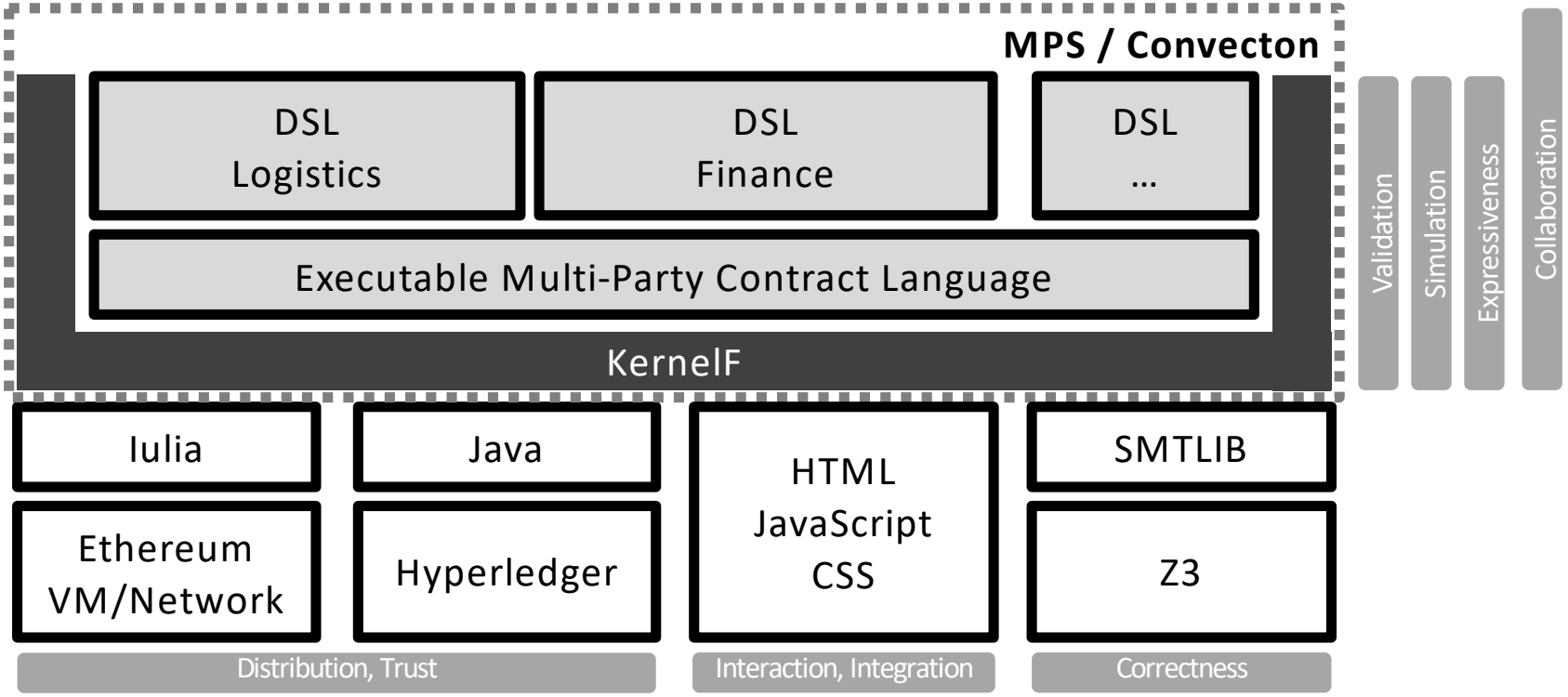
https://github.com/legalese/poets/blob/master/doc/hvitvedmaster.pdf

Domain-Specific Languages for Enterprise Systems

https://bitbucket.org/jespera/poets/raw/c0ee7194ce57d2ad6ca8894
8a44e88e546d5f4a/doc/poets-techreport/tr.pdf

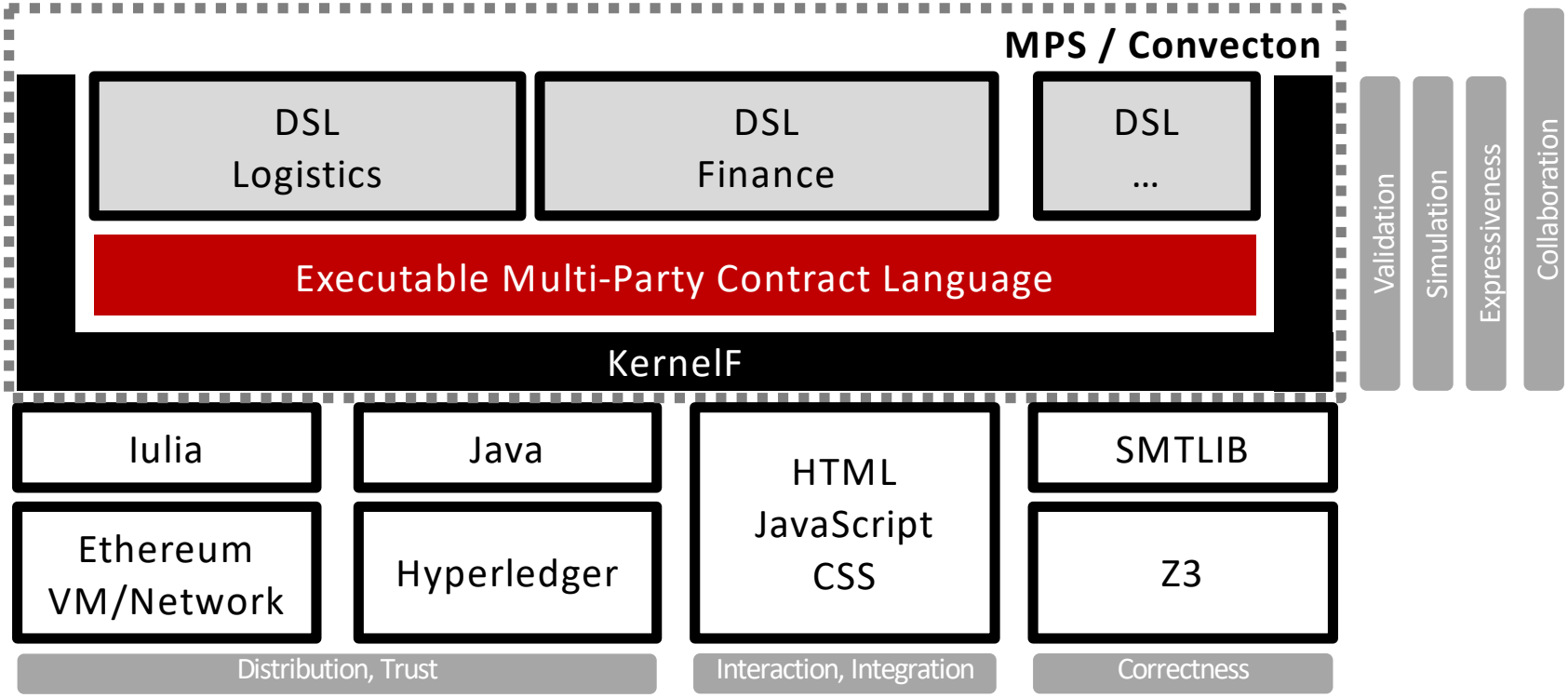
Solution

An Architecture For Smart Contracts



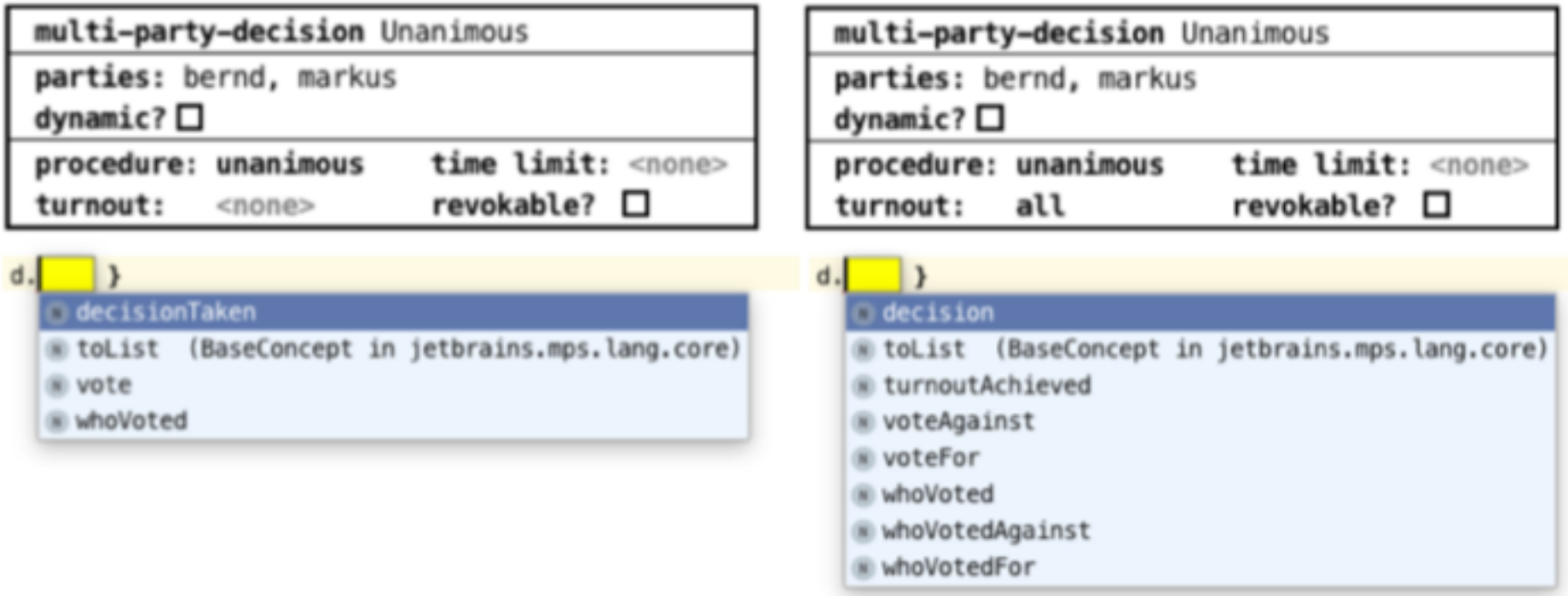
Generate to verification tools to build more confidence beyond type checking.

An Architecture For Smart Contracts



DEMO

Declarative Description



`MultiPartyBooleanDecision`

A declarative, configurable specification of how a number of parties makes a (Boolean) decision.

Execution and Test

A MPBD instance maintains the state of a decision process as it evolves over time.

Here, we play with an instance in the interactive REPL.

Combination with State Machines

More complex contracts are modeled as state machines; events are the API.

```
event openAccess  // go to the mode where we allow new guys to request to join
event requestAccess(newGuy: party) // a new guy wants to join the deciders
event terminateAccessRequest(who: party, newGuy: party) // kill a decision procedure
event voteForAccess(voter: party, newGuy: party) // vote for a new guy to become decider
event letsSell    // go to the state where we maintain the sell/no-sell decision
event voteForSelling(who: party)     // vote for the sale decision
event voteForStopSelling(who: party) // vote against the sale decision
```

Internally, the use BPBDs.

multi-party-decision Sale	
initial parties: bernd, klaus	
dynamic? ☒	sealable? ☐
procedure: unanimous	time limit: <none>
turnout: <none>	revokable? ☒

multi-party-decision AccessControl	
initial parties: bernd, klaus	
dynamic? ☒	sealable? ☐
procedure: majority	time limit: 20000
turnout: <none>	revokable? ☐

```
var sale                          = run(Sale)
var pendingAccess                 = box(map<party, AccessControl>())
observable query currentlySelling = sale.decisionTaken
```

Combintation with State Machines II

Here, a transition action creates a new AccessControl instance ...

```
on requestAccess(newGuy) [!isDecider/R(newGuy)] : {
  val acc = run(AccessControl)
  pendingAccess.update(it.put(newGuy->acc))
  acc.addParties(sale.registeredParties)
}
```

The state of that instance is then used in guard condition for the top level SM.

```
on voteForAccess(voter, newGuy) [isPending/R(newGuy) && isDecider/R(voter)] : {
  val acc = pendingAccess.val[newGuy]
  acc.vote(voter)
  if acc.decisionTaken then {
    sale.addParty(newGuy)
    pendingAccess.update(it.remove(newGuy))
  } else none
}
```

Preventing Game Theoretical Attacks

Only „valid“ senders can enter this state.

```
state playing [senderIs(players)] {
  on offerBid(money) : bids := bids.put(sender->money)
  ...
}
```

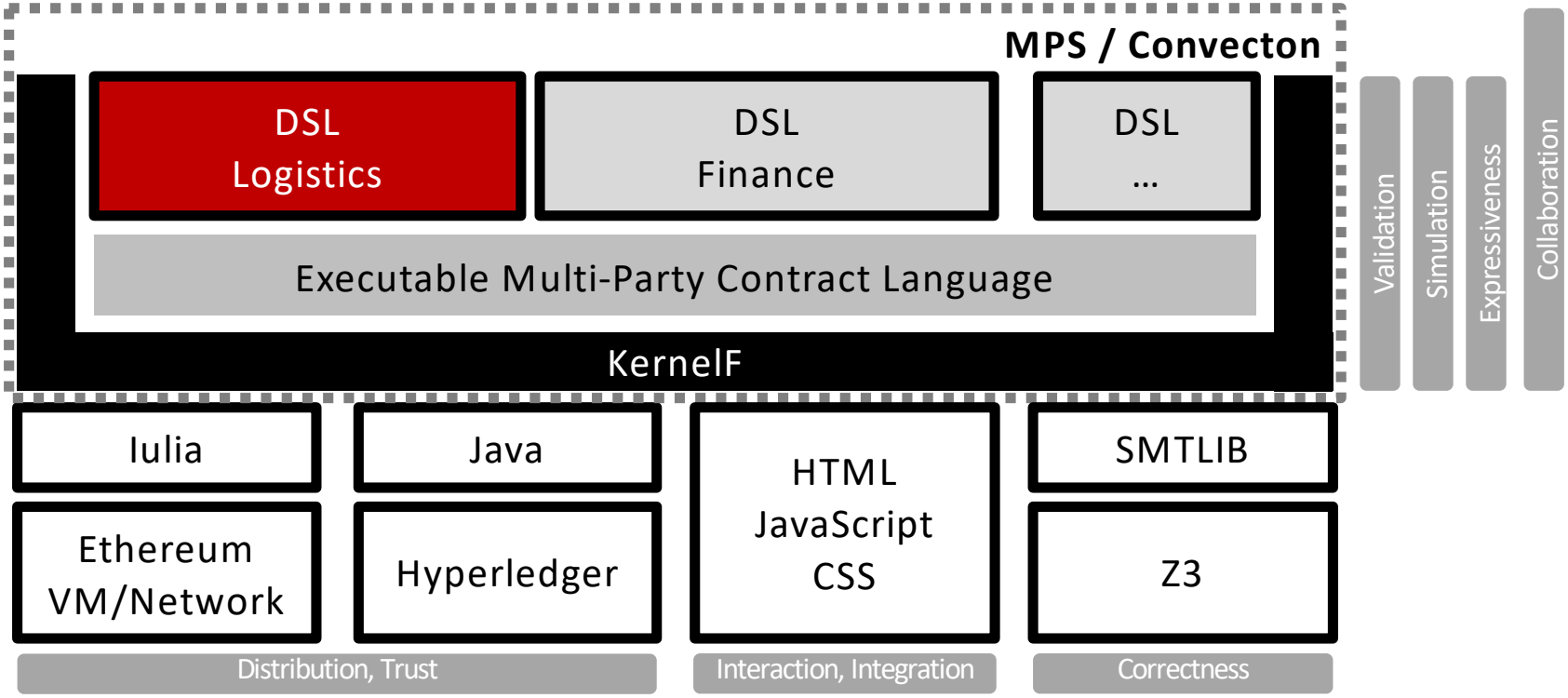
Events can only arrive at limited rate.

```
state requesting [rate(3/1000|commands-only)] {
  ...
}
```

States must be entered turn-by-turn.

```
state playing [senderIs(players)] {
  state bidding [takeTurns(players|ordered|after 1000 remove)] {
    on offerBid(money) : bids := bids.put(sender->money)
    if [timeInState > 2000] -> finished
  }
  ...
}
```

An Architecture For Smart Contracts



I D E A

Example: HyperCSL

SYNGRATO

Lisp (Clojure) based internal DSL for specification of general commercial contracts.

Inspired by Simon Peyton Jones and Jean-Marc Eber and the POETS group at CPHU and ITU in Denmark.

Uses Ken Adams' Categories of Contract

Language as fundametal semantic building blocks. Interpreter and UI in prototype stage.

Example: HyperCSL

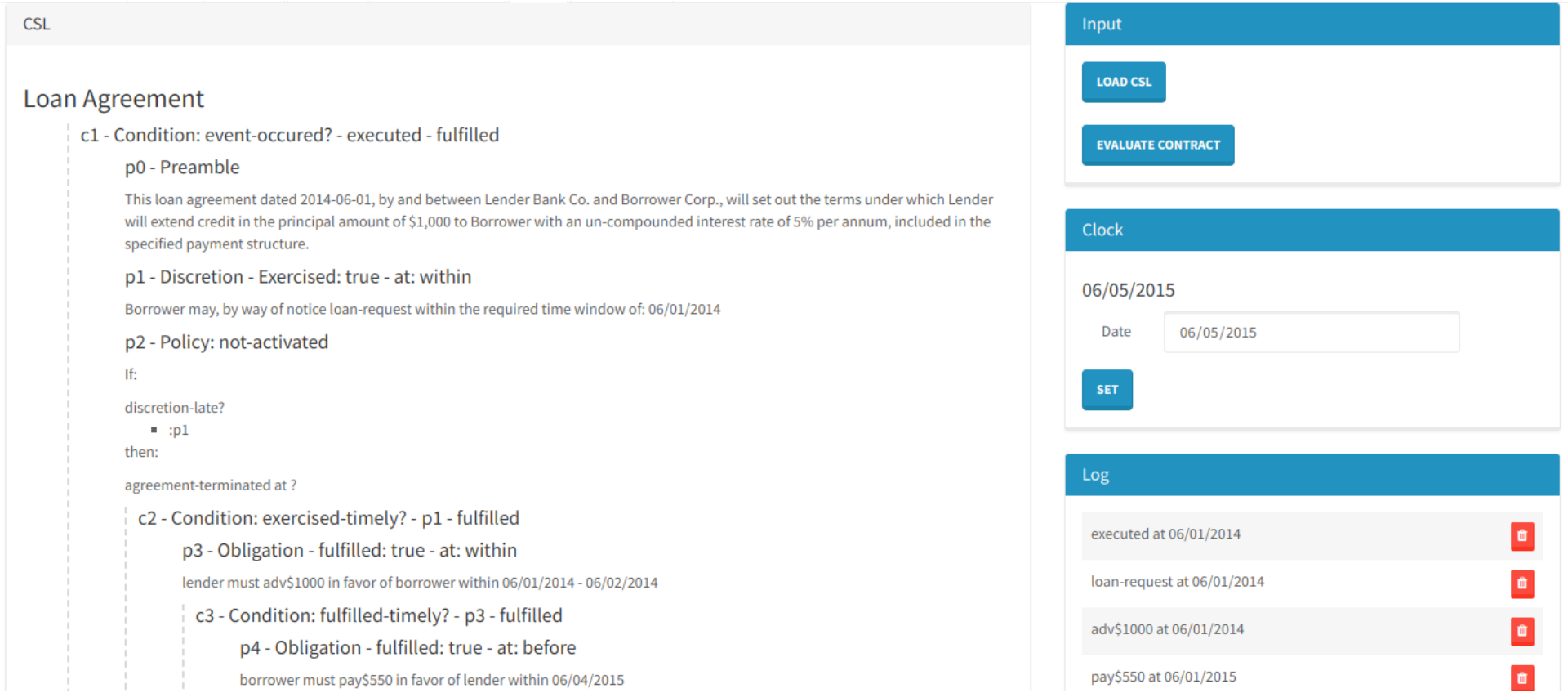
SYNGRATO

```
(con :c2
     (obs :exercised-timely? :p1)
     [(obli :p3
            "lender"
            "borrower"
            (action :payment (event :adv$1000) "Advance loan to borrower.")
            (tw (dt 2014 6 1) (dt 2014 6 2)))
      (con :c3
           (obs :fulfilled-timely? :p3)
           [(obli
             :p4
             "borrower"
             "lender"
             (action :payment (event :pay$550) "Repay first installment.")
             (obs :if (obs :event-occured? :event-of-default)
                  (tw (obs :first-time-of :event-of-default))
                  (tw (dt 2015 6 1))))
            (obli
             :p5
             "borrower"
             "lender"
             (action :payment (event :pay$525) "Repay second installment.")
             (obs :if (obs :event-occured? :event-of-default)
                  (tw (obs :first-time-of :event-of-default))
                  (tw (dt 2016 6 1))))])])
```

Example: HyperCSL

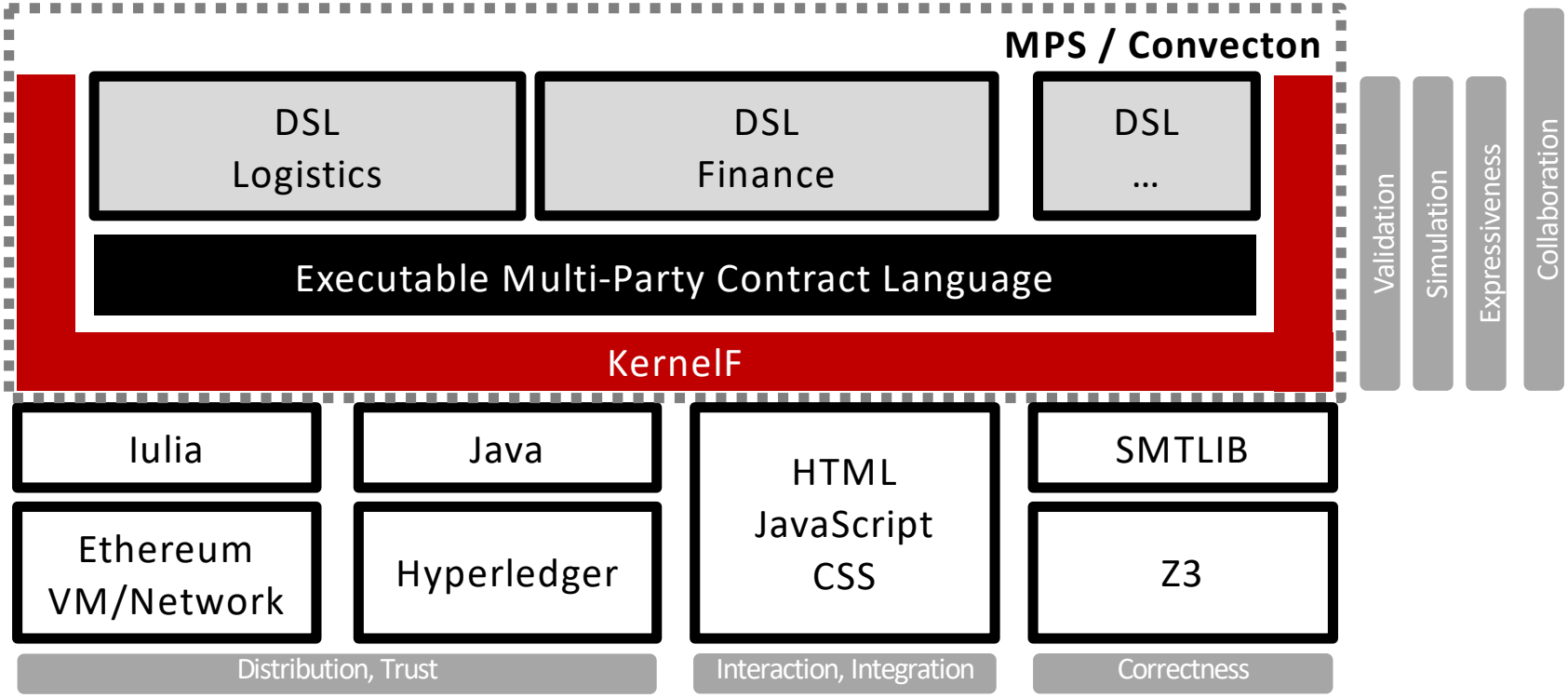
SYNGRATO

A UI to visualize the interactive execution of CSL contracts.



Tooling

An Architecture For Smart Contracts

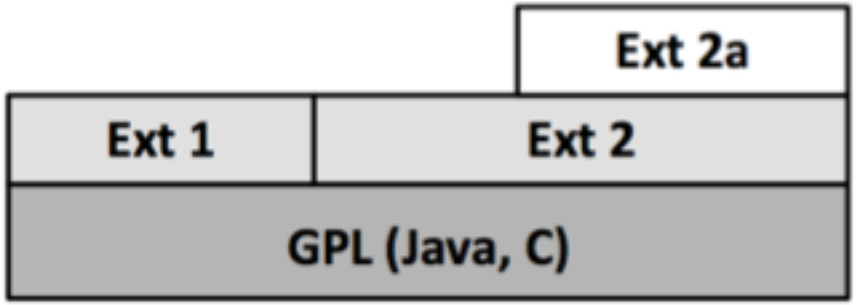


KernelF is an extensible functional language used at the core of DSLs.

DSL Development

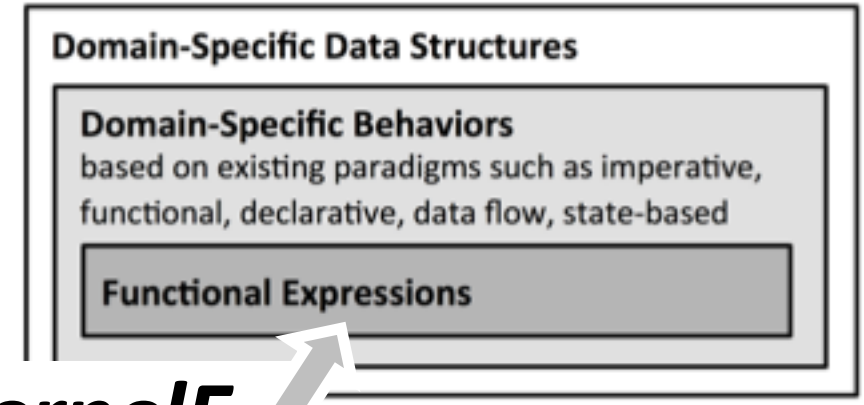
GPL Extension

Reuse GPL incl. Expressions and TS
Add/Embed DS-extensions
Compatible notational style
Reduce to GPL



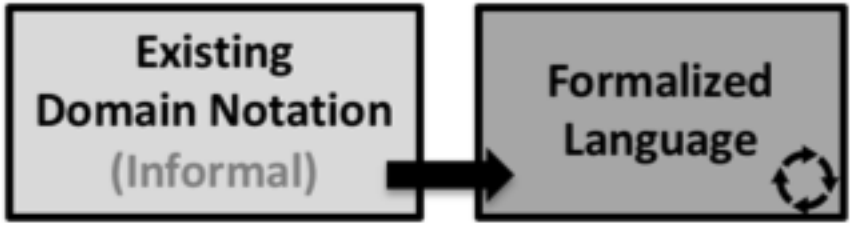
New Language

Analyze Domain to find Abstractions
Define suitable, new notations.
Rely on existing behavioral paradigm
Reuse standard expression language
Interpret/Generate to one or more GPLs



Formalization

Use existing notation from domain
Clean up and formalize
Generate/Interpret
Often import existing „models“



Functional Features

Functional, no state at its core.

Purity + Effect Tracking

The usual types, literals and op's

Various Conditionals

Functions and Blocks

No `null`, only opt<T>

Error Handling `attempt<T|E-1,... E-n>`

```
try <e> => <s> error <E-1> => <e-1> ... error <E-n> => <e-n>
```

Immutable Collections and higher-order functions

Enums, tuples, records, all immutable

Constraints on types and functions

Stateful Features

Boxes (like Clojure's `ref`)

Transactional Memory

State Machines

Interactors

Extensible/Embeddable through modular language implementation and other means.

(Meta-) Tooling

Language Workbench

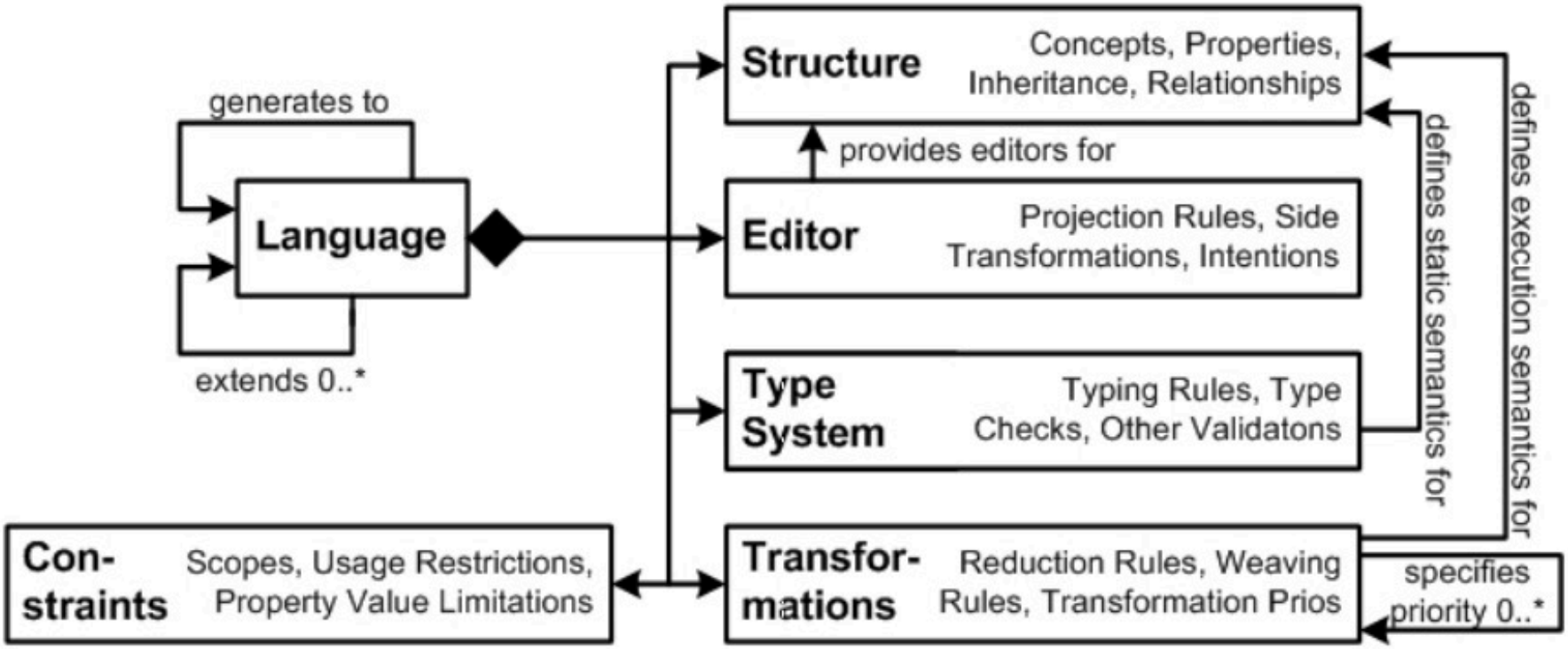
Open Source, by Jetbrains

Very Powerful

Used for years by itemis and others

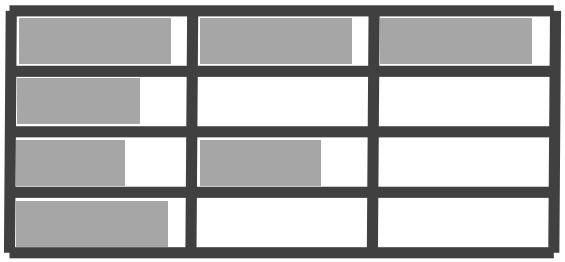
Vast Experience

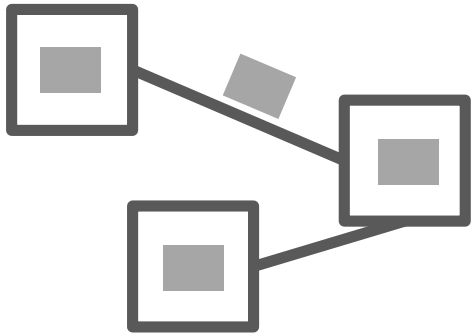
MPS: Language Toolkit



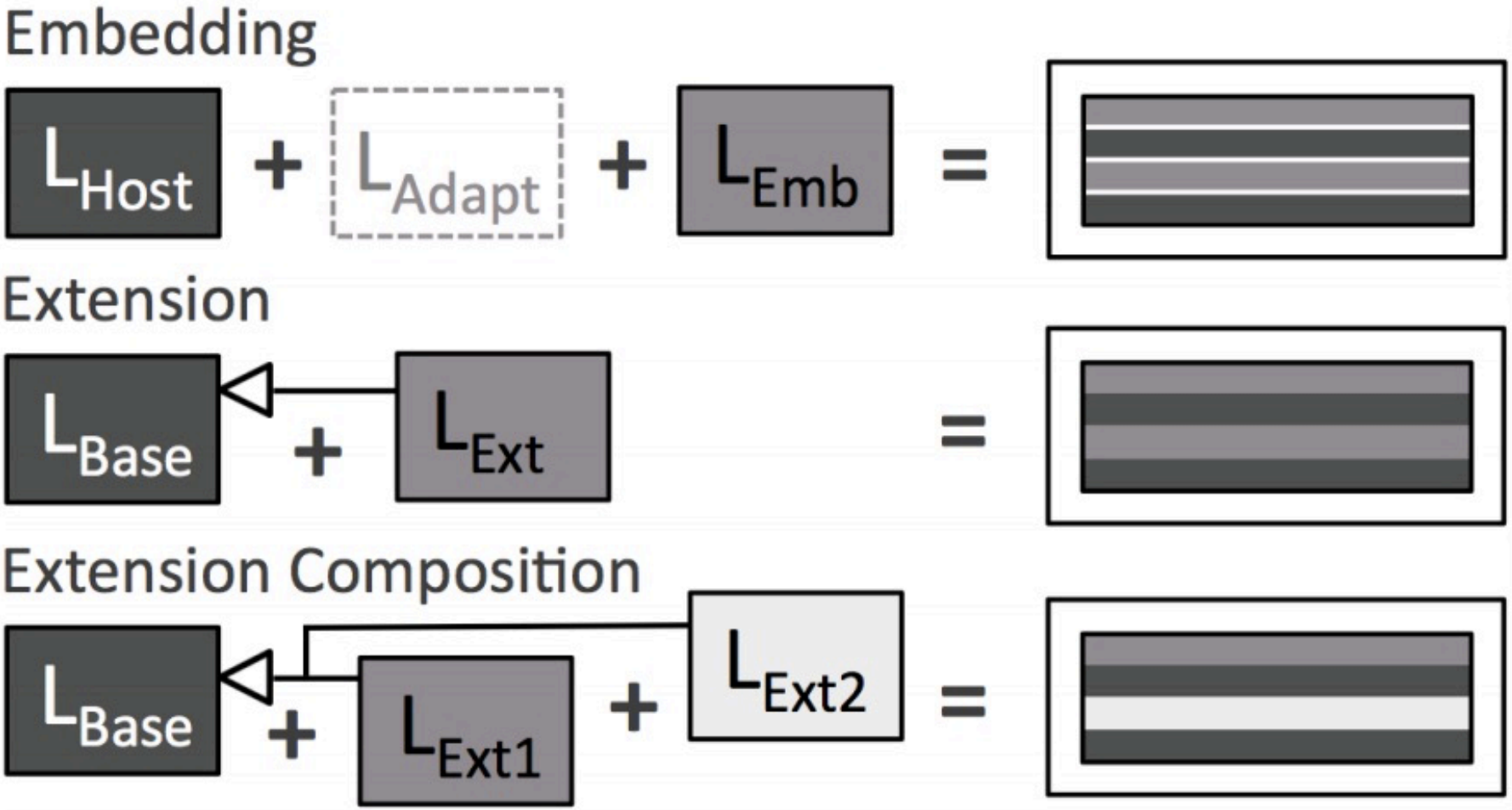
+ Refactorings, Find Usages, Syntax Coloring, Debugging, ...

MPS: Notational Freedom



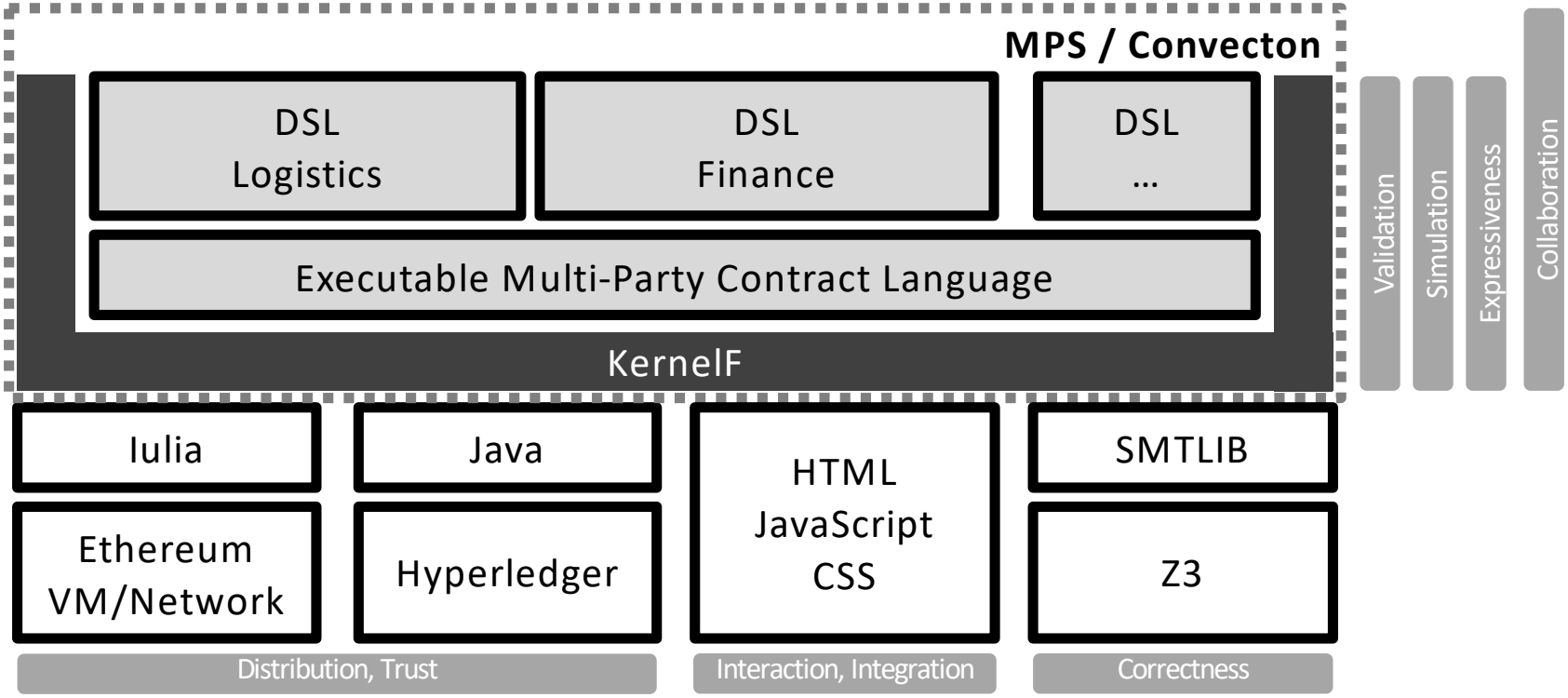


MPS: Language Composition

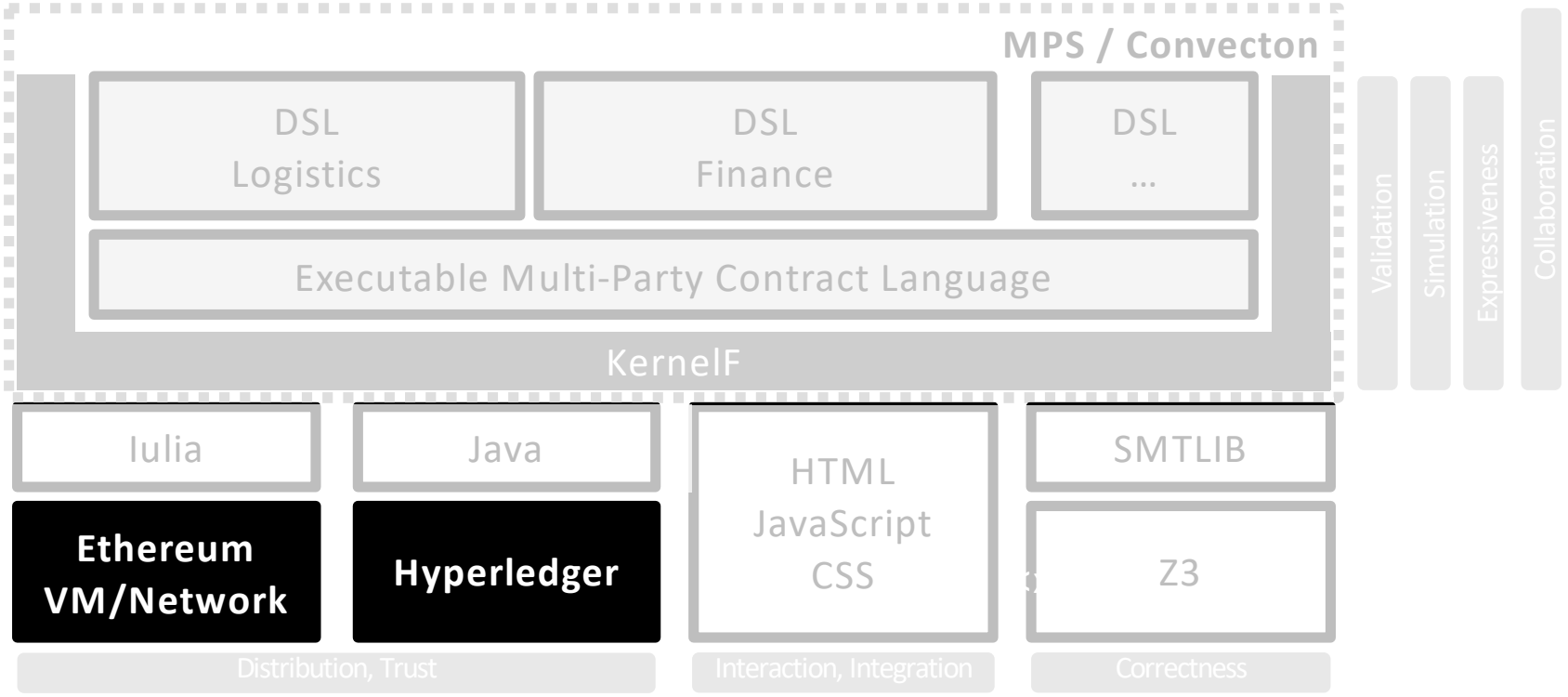


Verifying Infrastructure

An Architecture For Smart Contracts



An Architecture For Smart Contracts



TRUST?

Verifying Blockchain Infrastructure

Formal Semantics of the EVM in K

https://www.ideals.illinois.edu/bitstream/handle/2142/97207/hildenbrandt-saxena-zhu-rodrigues-guth-daian-rosu-2017-tr_0818.pdf

IELE: Register-Based VM for the Blockchain

https://runtimeverification.com/blog/new-technologies-for-the-blockchain-iele-virtual-machine-and-k-universal-language-framework/

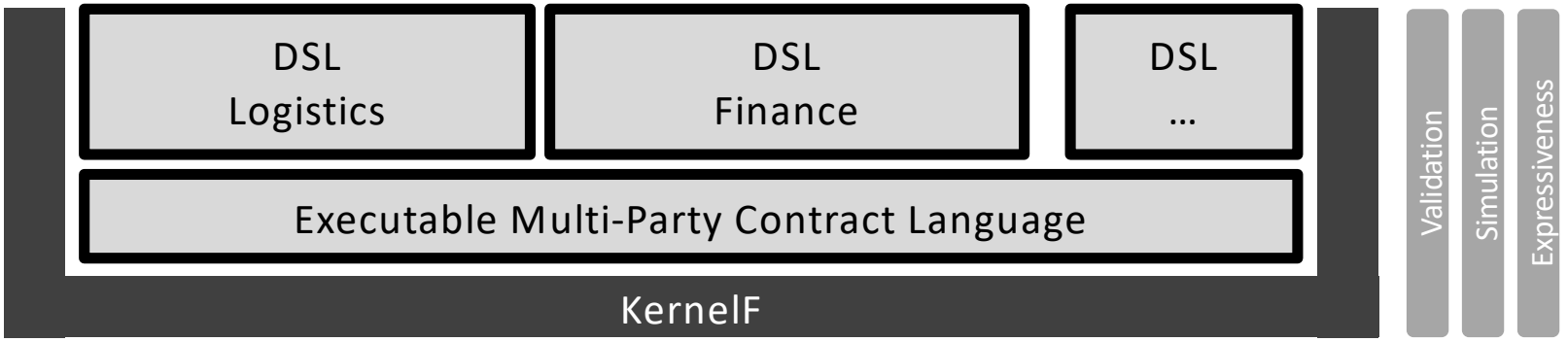
ERC20-K: Formal Executable Spec of ERC20

https://github.com/runtimeverification/erc20-semantics

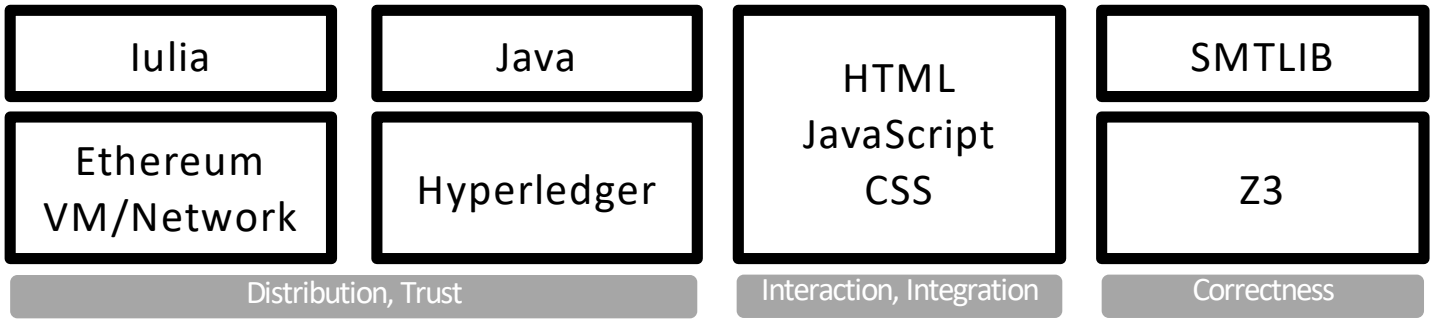
Formal Verification for Solidity Contracts

https://forum.ethereum.org/discussion/3779/formal-verification-for-solidity-contracts

An Architecture For Smart Contracts



Did I program/specify the right behaviors?



Will the infrastructure execute the behaviors faithfully?

An Architecture For Smart Contracts

Validation

Ensure that the program does the correct things, wrt. to the requirements.

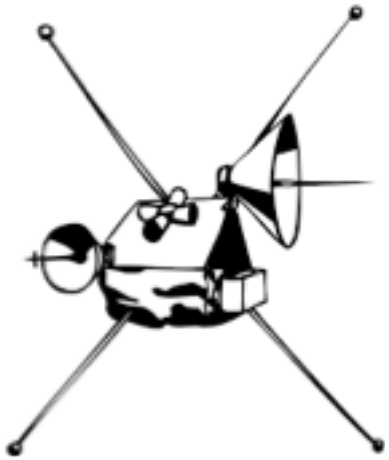
Did I program/specify the right behaviors?

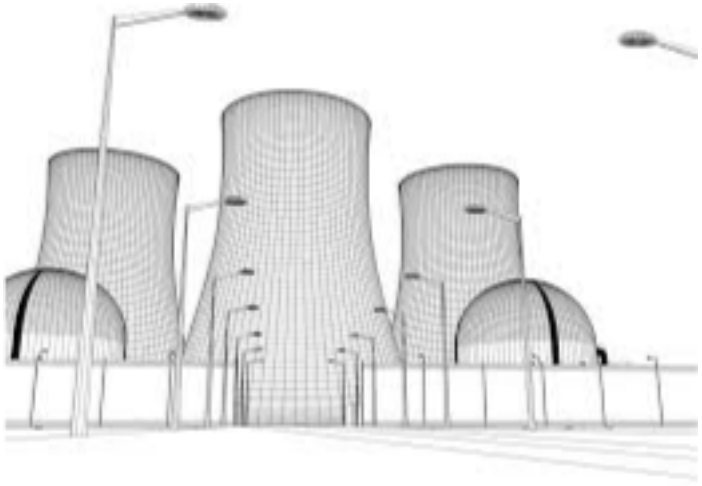
Verification

Ensure that the program performs correctly the things the program text tells it to do.

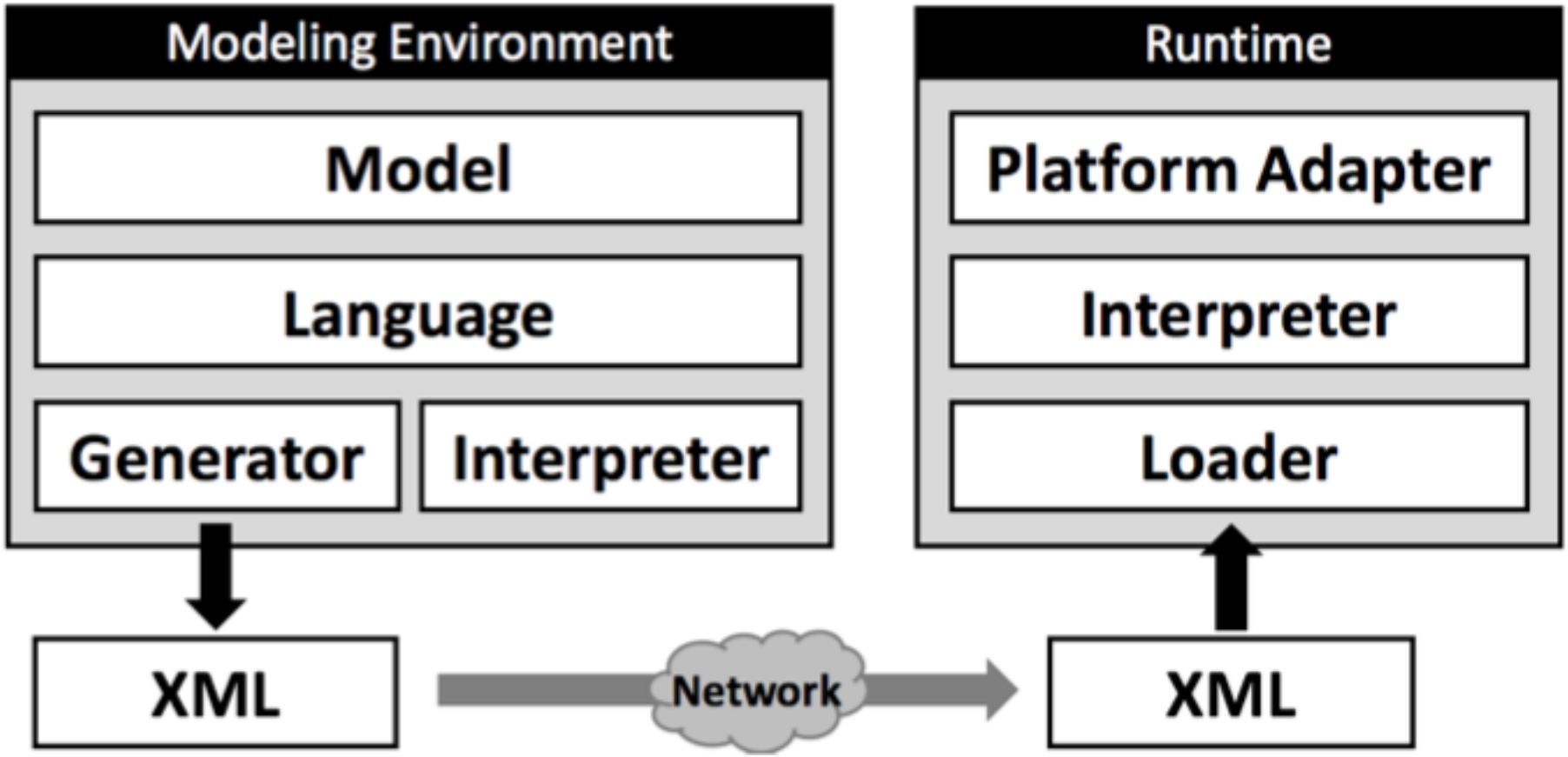
Will the infrastructure execute the behaviors faithfully?

Not the first community to realize ... ☺



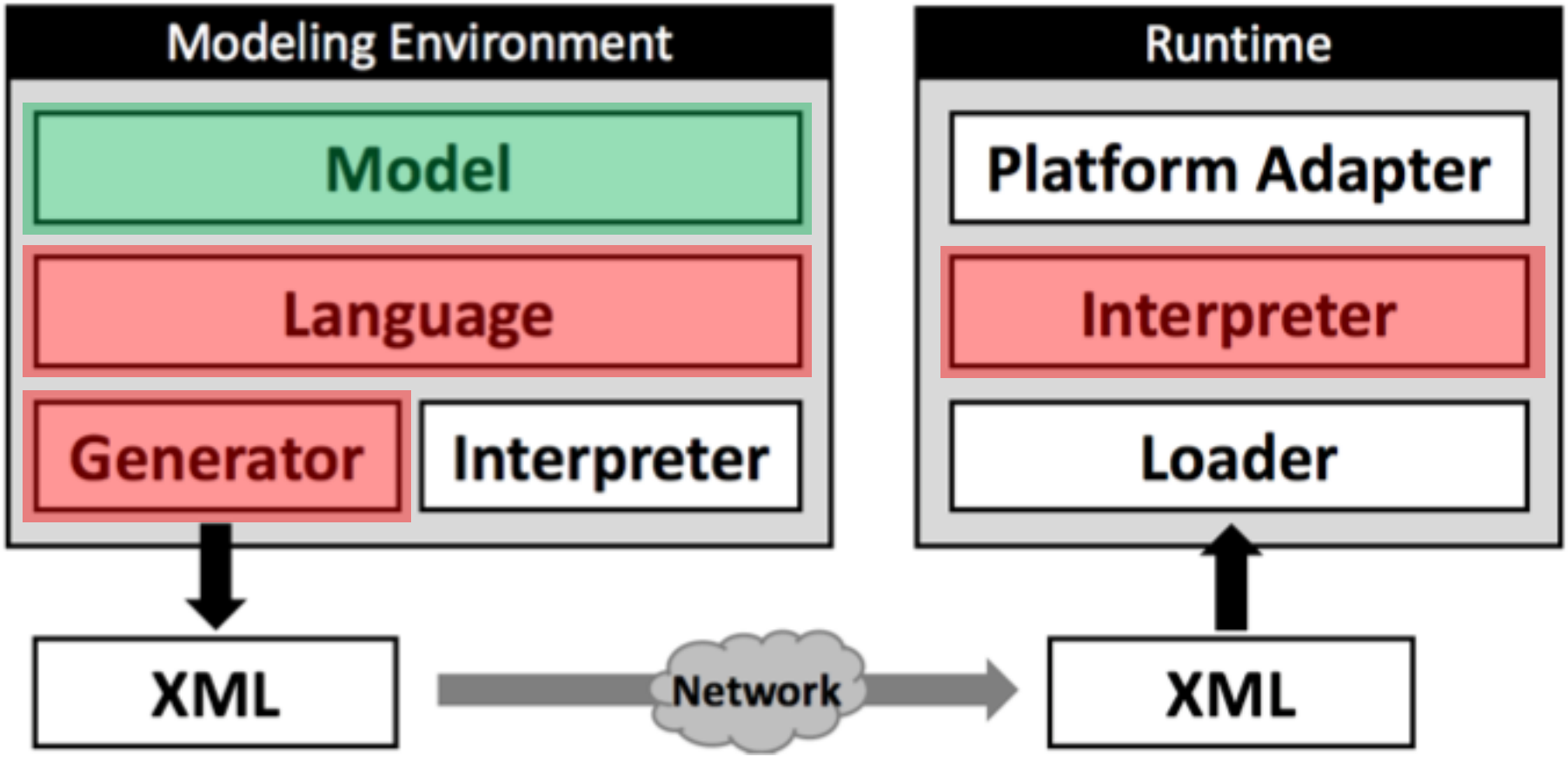


Sidebar: System Architecture



What good is all the abstraction if we cannot trust the translation to the implementation?

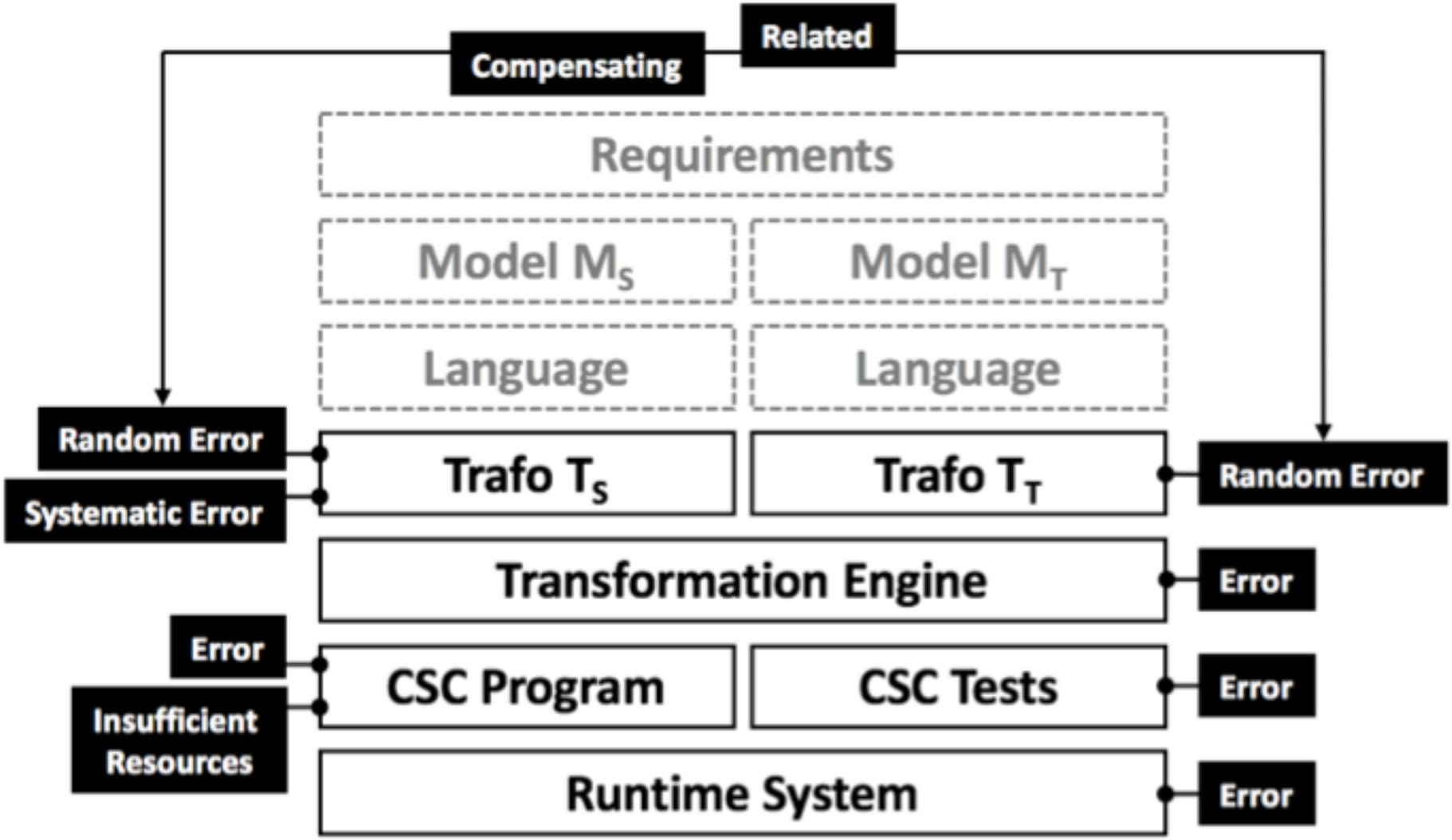
Sidebar: System Architecture



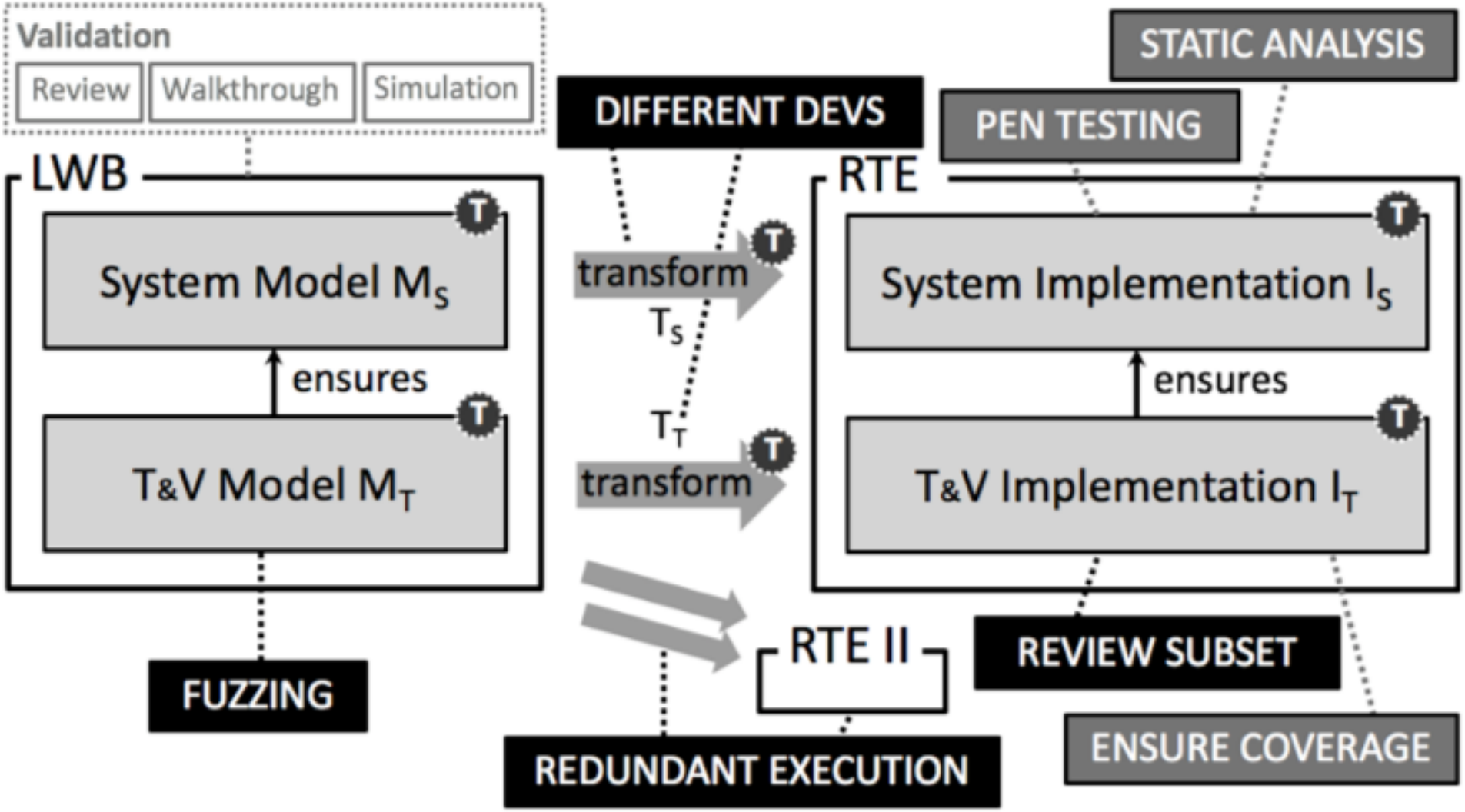
Tools may introduce *additional systematic errors* if faulty.
Safety **standards** require reliable mitigation of such errors.

DO-178C EN50129 IEC62304 ISO26262

Risk Analysis



Mitigations – Safe Architecture



Wrap Up

Further Reading

Mutable State in KernelF

https://medium.com/@markusvoelter/dealing-with-mutable-state-in-kernelf-e0fdec8a489b

A Smart Contract Development Stack

https://languageengineering.io/a-smart-contract-development-stack-54533a3a503a

A Smart Contract Development Stack, Pt. 2

https://languageengineering.io/a-smart-contract-development-stack-part-ii-game-theoretical-aspects-ca7a9d2e548d

KernelF Reference

http://voelter.de/data/pub/kernelf-reference.pdf

DSLs in Safety-Critical Development

http://voelter.de/data/pub/MPS-in-Safety-1.0.pdf

Contracts must be functionally correct
in order for stakeholders to trust them.

We need better languages
to describe contracts in a meaningful way

Integration of verification tools
can be an important step to assure correctness

Simulation, Experimentation and Test
should be available in an interactive, local environment

Deployment to Blockchain is non-func,
it provides guarantees beyond functionality

Other deployments are useful,
that provide other trade-offs (secure⬇, fast⬆)