Access Control Policies Across Abstraction Layers

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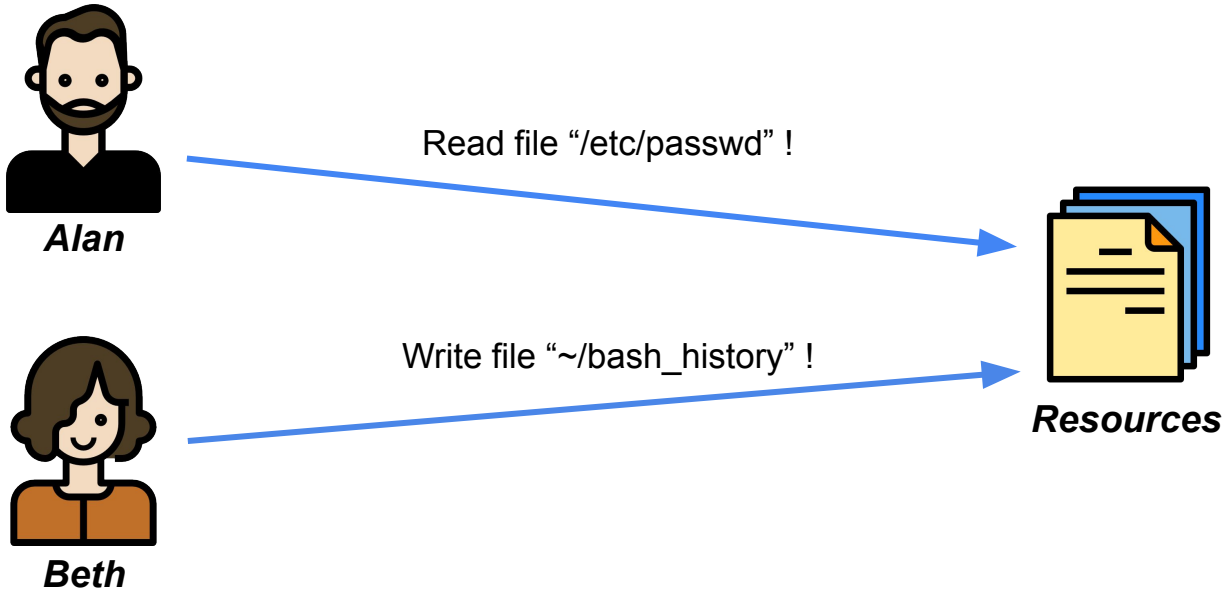
Recap - Access Control



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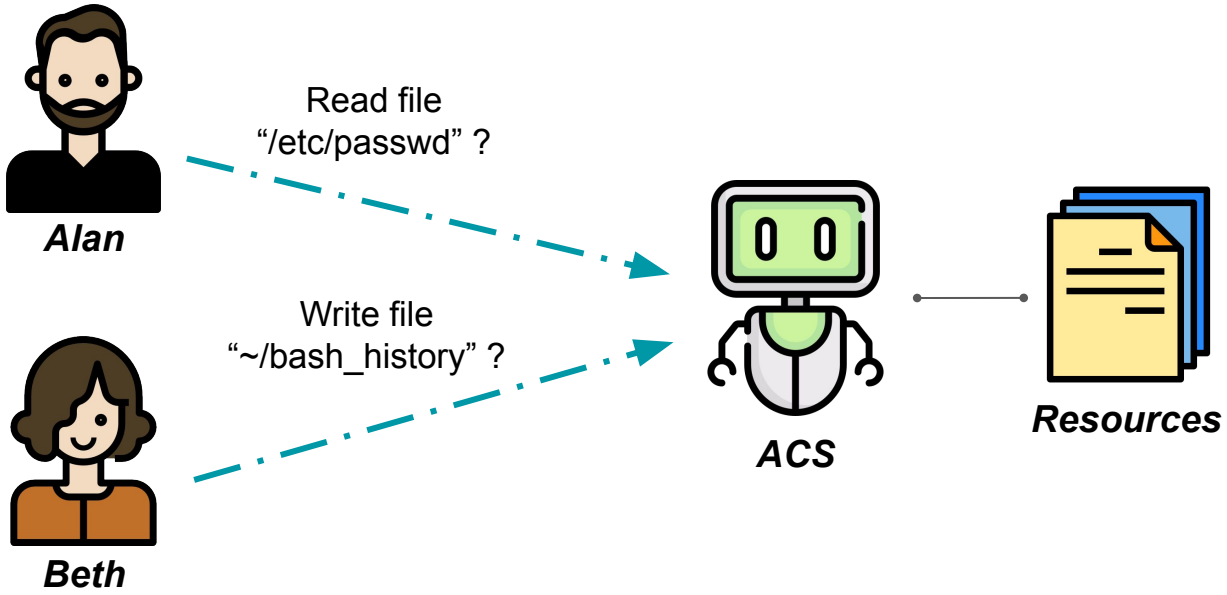

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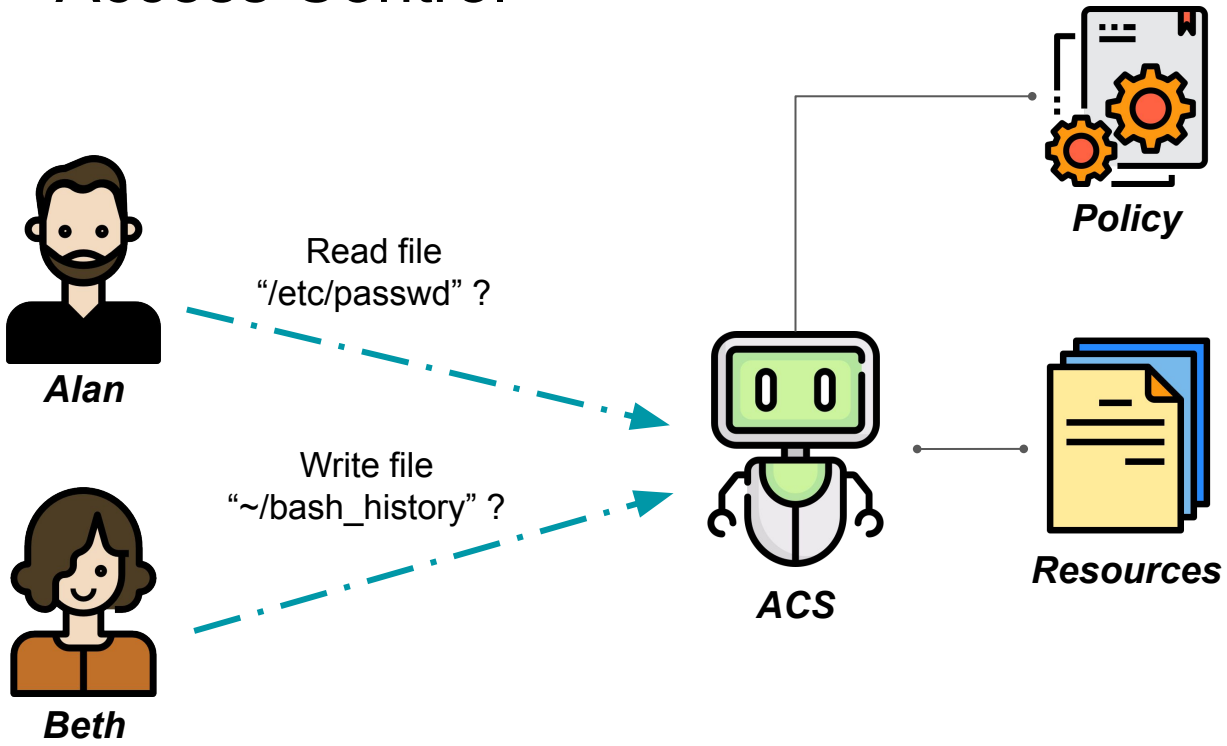

Access Control - Where?

- **Networks**: Firewalls
- **Web**: XACML
- **Social Networks**: ReBAC
- **Operating Systems**: ACLs, SELinux
- **Medium - Large Enterprises**: RBAC
- ...

Tasks

- **Collecting Requirements**
- **Defining a Specifications**
- **Coding the Configuration**
- **Verification and Analysis**
- **Testing**
- **Update (specifications and Configuration)**

Tasks - Abstraction Layers

- **Collecting Requirements**
- **Defining a Specifications**
- **Coding the Configuration**
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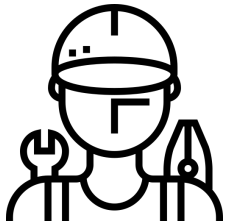
- **Testing**
- **Update (specifications and Configuration)**

High Level

Specification Language
Easy to Write & Read
Cannot Run

Low Level



Configuration Language
Hard to Write & Read
Actually Run

Problems

Manual coding is

- error prone - misunderstanding
  - of the specifications – e.g. ignore corner cases
  - of the configuration – e.g. low level intricacy
- expensive

Configurations and Specifications may change over time

Specifications may be impossible to implement

… we propose different solutions for mitigating these problems on three contexts

Two-way Translation Based Solution

- Compilation & Decompilation
  - Grant coherence
  - Automatise Coding & Analysis
- Support configuration and specification changes
- Low Level configuration is automatically produced, but can also be modified by hand

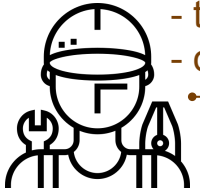
- specify
- verify
- update

High Level Language

compile

project limitations

decompile



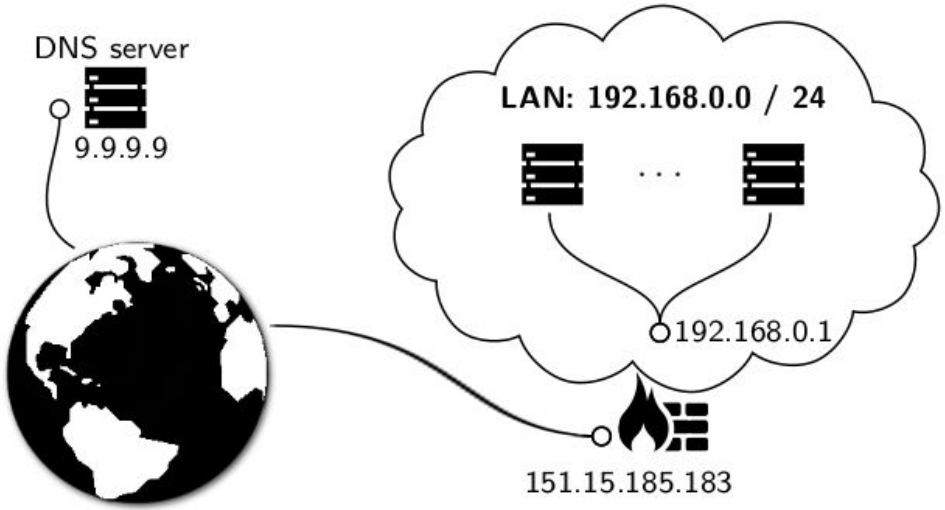
- tune
- test
- optimize

Low Level Language

Firewalls

On boundaries of the networks, **filter** and **translate** packets (NAT)

Different low level languages (*iptables*, *pf*, *ipfw*). Difficult to read and write, with low level details like shadowing and tags



"Connection from internal hosts to a DNS Server are redirected to 9.9.9.9"

FWS/F2F

- specify
- verify
- update

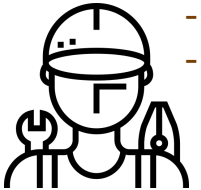
FWQL

- Function over IP packets
- SQL like interface

compile

project limitations

decompile



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Firewall Languages

- iptables, ipfw, pf, …
- tag, shadowing, …

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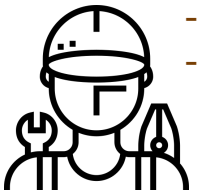

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Firewall Languages

- iptables, ipfw, pf, …
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"Connection from internal hosts to a DNS Server are redirected to 9.9.9.9"

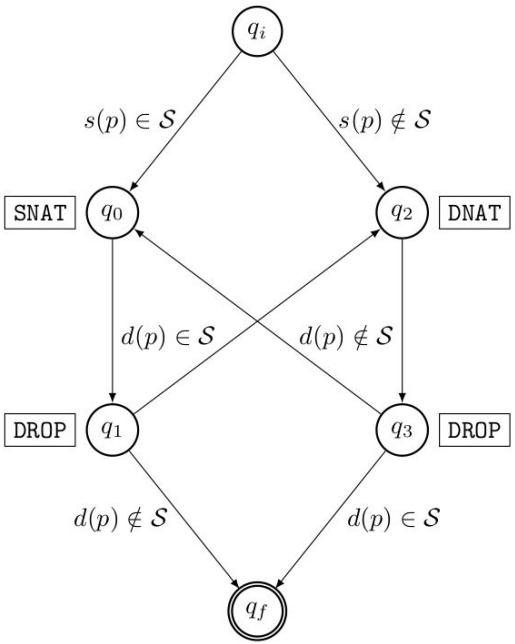
```
update t_dst = 9.9.9.9 in TAB where
     ( ( srcIp = Internal)
          and dstPort = DNS )
```

```
*nat
-A PREROUTING -p udp -s 192.168.0.0/24
     -- dport 53 -j DNAT -- to 9.9.9.9

*filter
-A FORWARD -m state -- state
     ESTABLISHED -j ACCEPT
-A INPUT -m state -- state
     ESTABLISHED -j ACCEPT
-A FORWARD -p udp -s 192.168.0.0/24
     --dport 53 -j ACCEPT
-A INPUT -p udp -s 192.168.0.0/24
     --dport 53 -j ACCEPT
```

Intermediate Firewall Configuration Language - IFCL

System Evaluation Algorithm



Configuration

Ruleset: list of pairs (Predicate, Action)

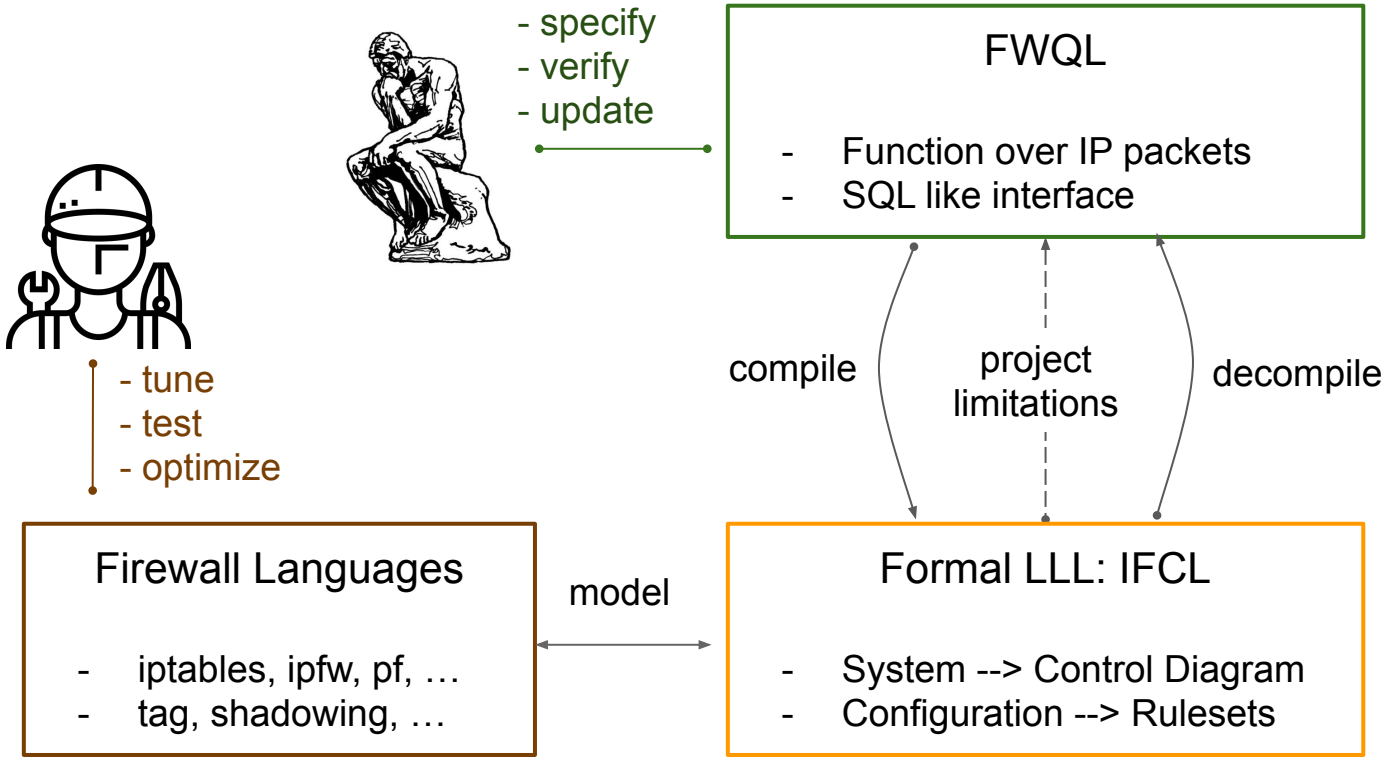
Action in

ACCEPT	RETURN
DROP	NAT(n_d, n_s)
CALL(R)	MARK(m)
GOTO(R)	CHECK-STATE(X)

Rulesets Association

$$c_{pf}(q_i) = R \qquad c_{pf}(q_0) = R_{snat} \qquad c_{pf}(q_2) = R_{dnat}$$
$$c_{pf}(q_f) = R \qquad c_{pf}(q_1) = R_{fout} \qquad c_{pf}(q_3) = R_{finp}$$

FWS/F2F - Tool


- specify
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FWQL
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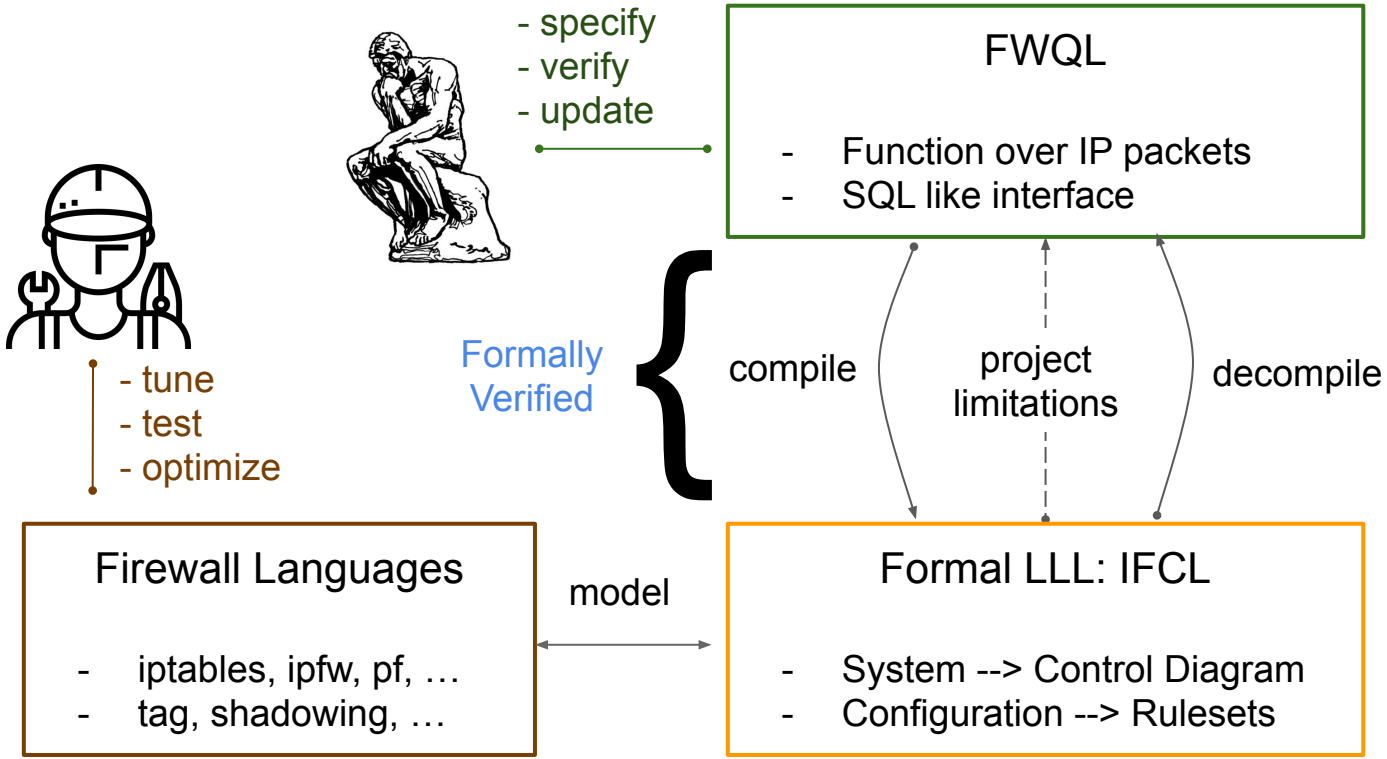
- SQL like interface
compile
project limitations
decompile
- tune
- test
- optimize
Firewall Languages
- iptables, ipfw, pf, …
- tag, shadowing, …
model
Formal LLL: IFCL
- System --> Control Diagram
- Configuration --> Rulesets

FWS/F2F - Tool


- specify
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FWQL
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- test
- optimize
Formally Verified
compile
project limitations
decompile
Firewall Languages
- iptables, ipfw, pf, …
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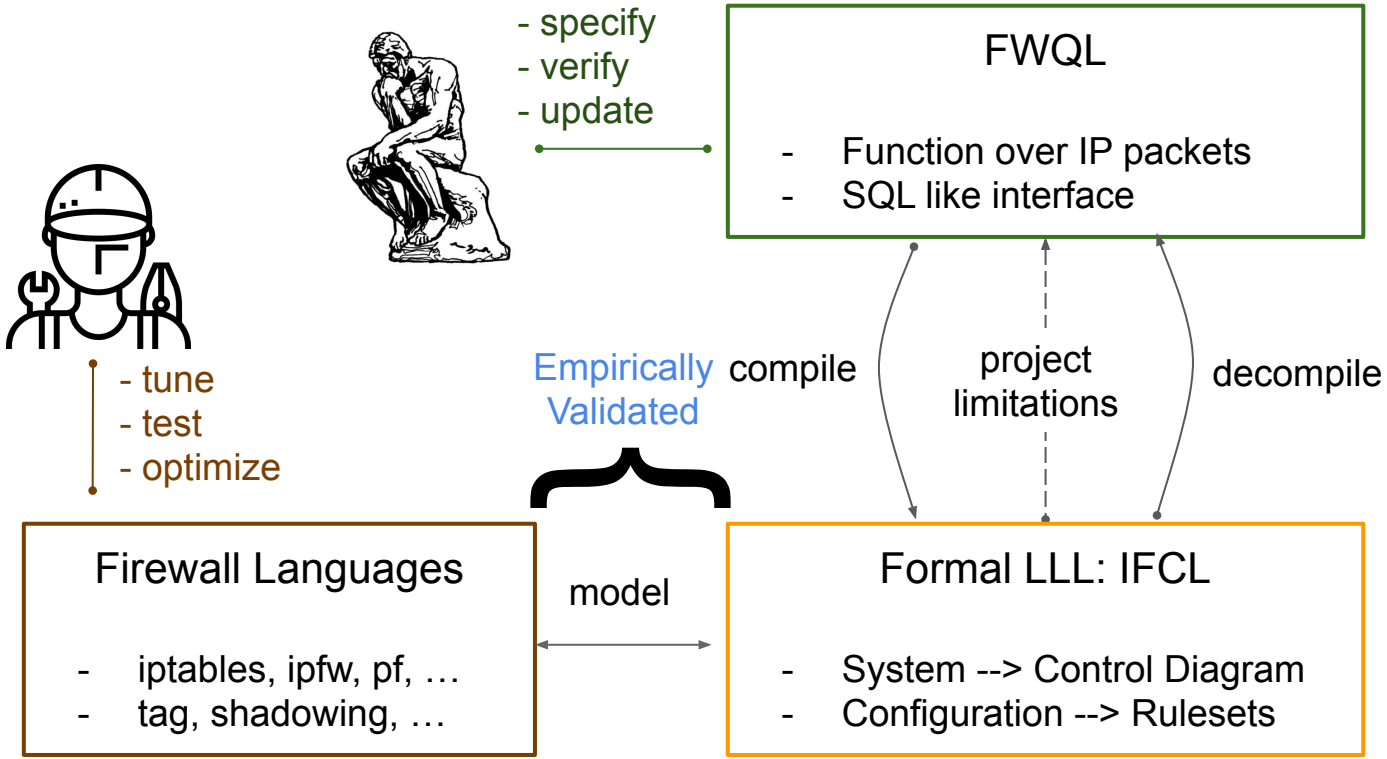
- specify
- verify
- update
FWQL
- Function over IP packets
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- tune
- test
- optimize
Empirically Validated
compile
project limitations
decompile
Firewall Languages
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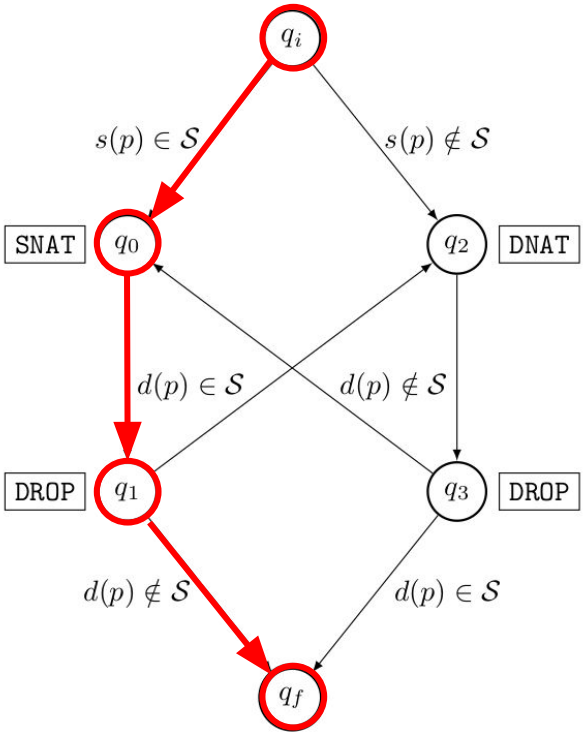
Expressivity Problem

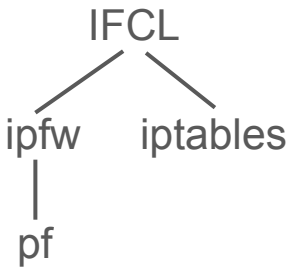


Individual Expressivity

pf cannot apply Destination NAT (**DNAT**) on packets following the path in red

Functional Expressivity

packet p accepted with SNAT
packet p' dropped
what if p after SNAT is equal to p' in q_1?



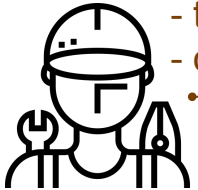
Verification Based Solution

- Configuring by hand
- Verification procedure guarantees coherence between high and low level
- Support specification and configuration changes
- When compilation would be risky (security critical low level details)

- specify
- verify
- update

High Level Language

verify coherence



- configure
- test
- optimize

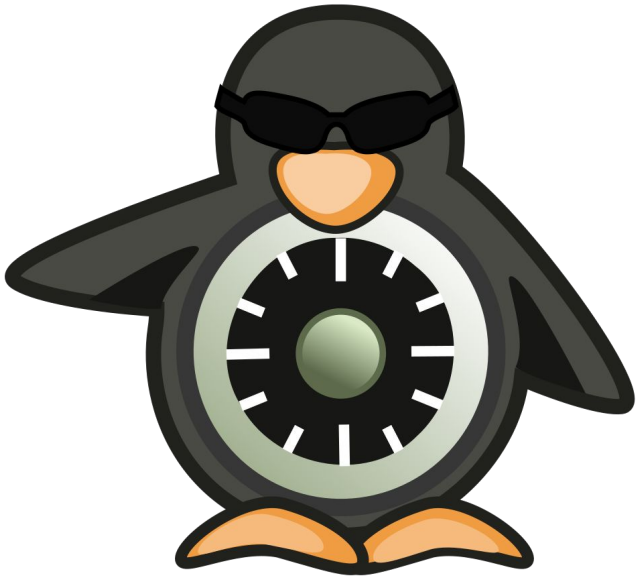
Low Level Language

SELinux CIL

SELinux policy defines mandatory access control for the applications, processes, and files on a Linux system.

Used from Servers to Android devices

CIL allows to structure configurations using macros and blocks



SELinux - Notoriously a Nightmare

- OS entities and operations are numerous and varied
- Configurations are huge

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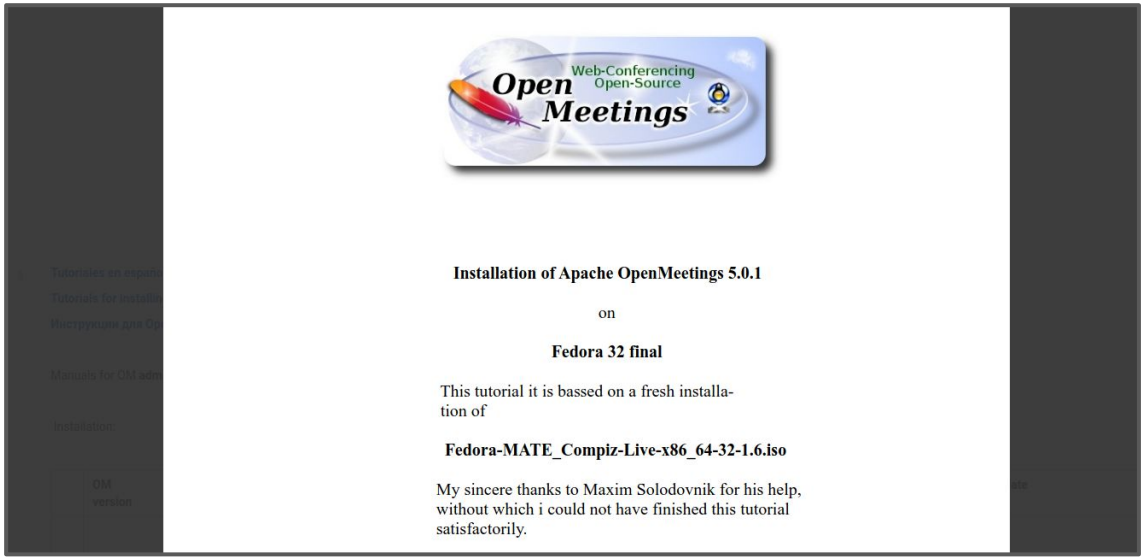

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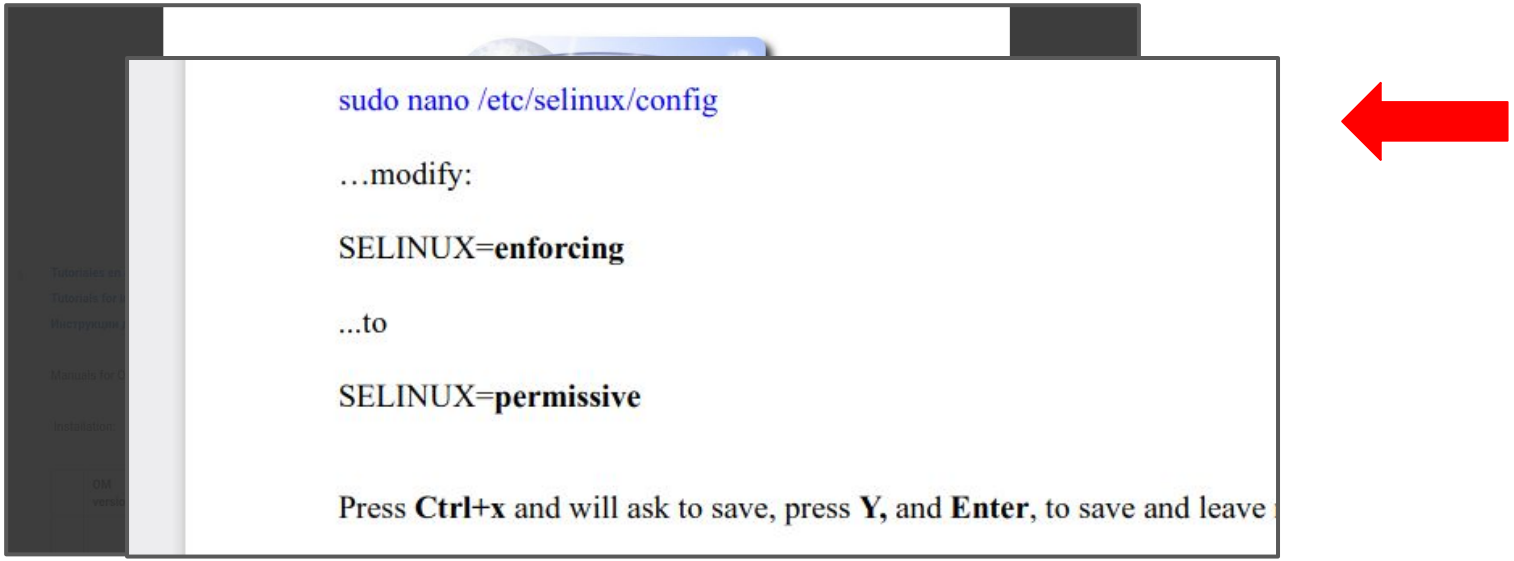


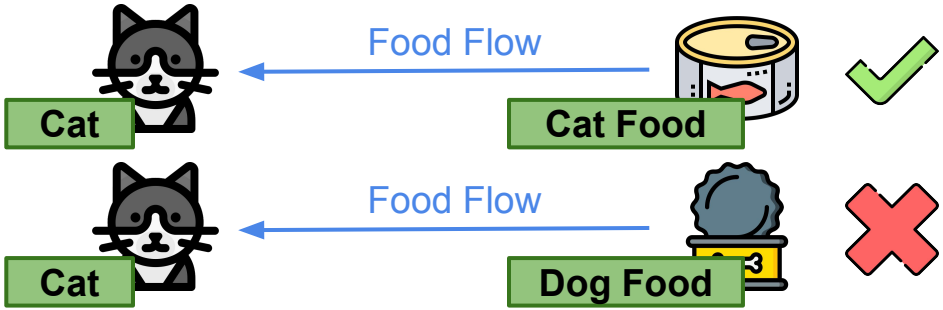
SELinux - Low Level Configurations

- Every part of the OS is associated with Types
- A set of Operations are defined
- Rules “Type x can perform Operation a on Type y”

Types: Dog, Cat, Dog Bowl, Cat Bowl

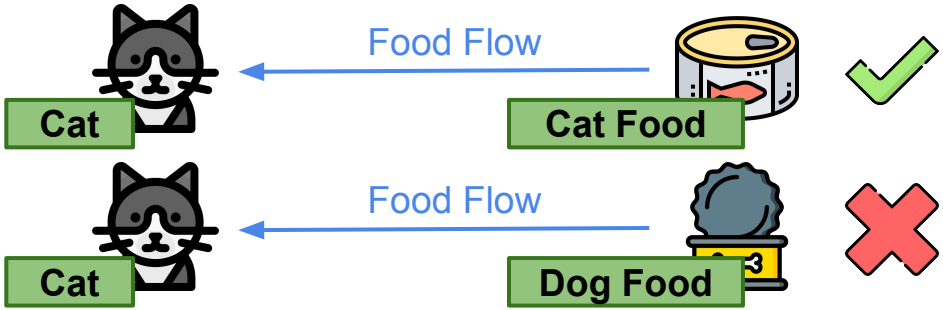
SELinux - High Level Specifications

Flow properties:

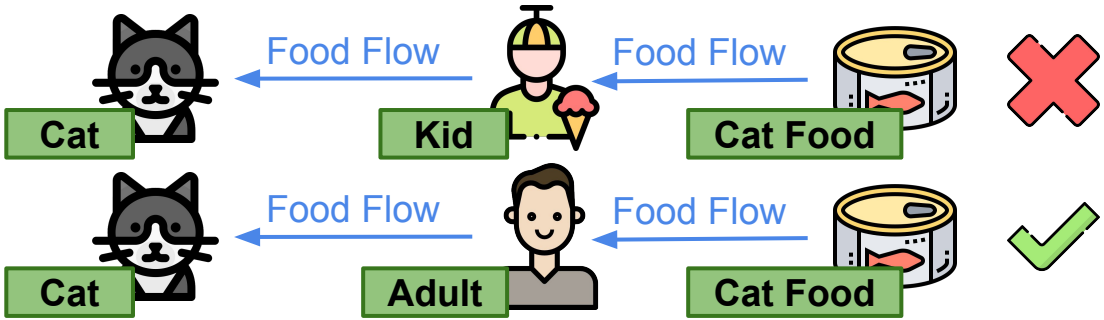


SELinux - High Level Specifications

Flow properties:

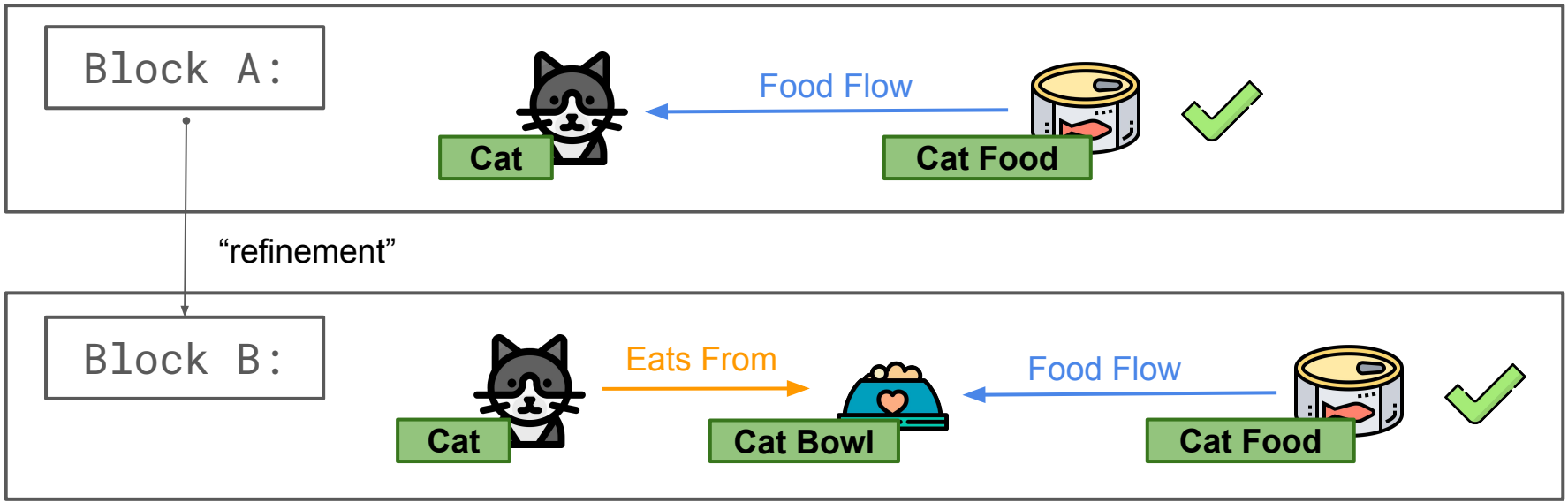


Intransitive Flow Properties:



SELinux - High Level Specifications

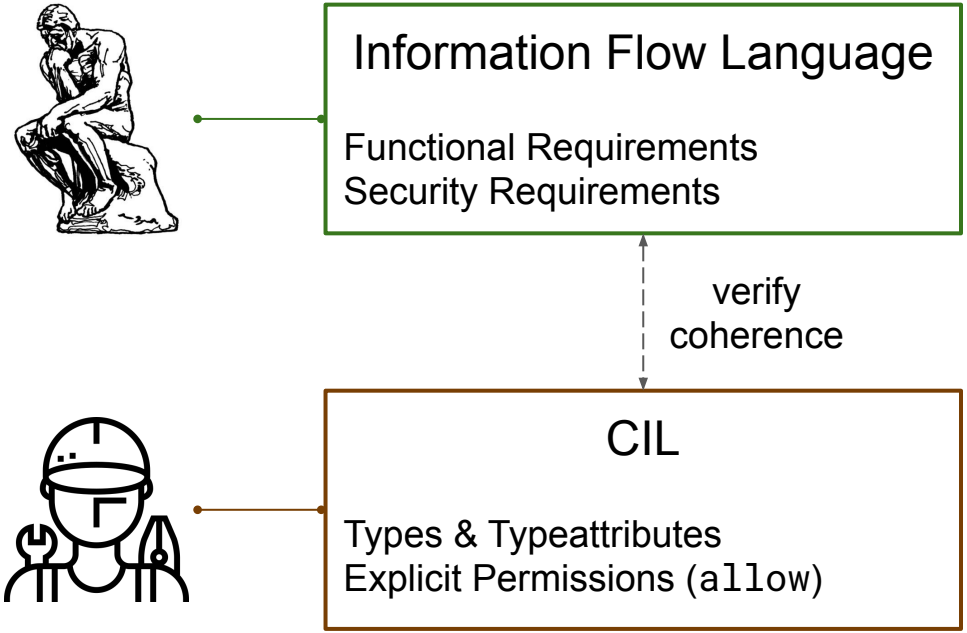
Flow properties allow Policy Engineering:



SELinux IFCIL

IFCIL extends CIL with IFL requirements that are first class citizens

A verification procedure grants that the actual permissions satisfies the requirements



IFCIL - Example

```
(macro anonymize((type x) (type y))
    (type anon)
    (allow anon x (file (read)))
    ;IFL; (S1) x +> y : x > anon +> y ;IFL;)

(type DB)
(type http)
(type net)

;IFL; (F1) DB +> http +> net ;IFL;
;IFL; (F2) net +> http +> DB ;IFL;

(call anonymize(DB net))

(allow http anon (file (read)))
(allow http DB (file (write)))
(allow http net (file (read write)))
```

IFCIL - Example

CIL

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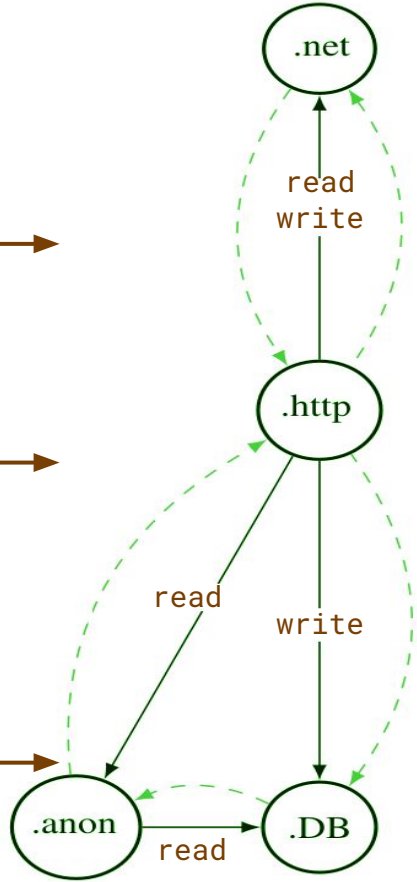

IFCIL - Example

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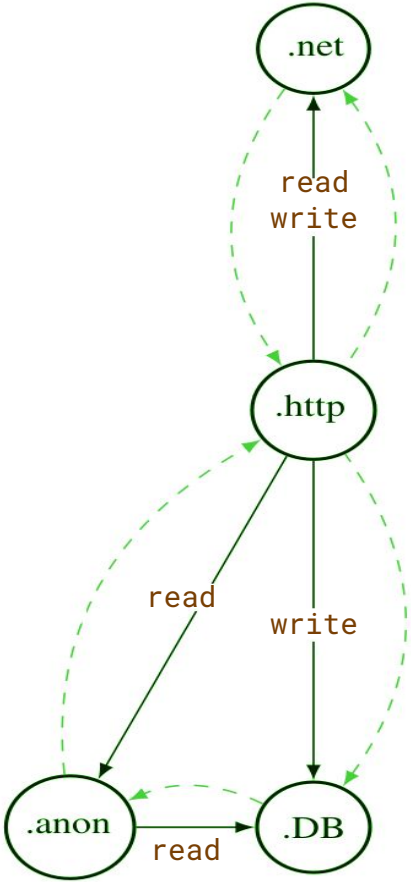
```

IFCIL encoded as NuSMV configuration file :

- Permissions as Kripke Transition System
- Requirements as LTL formulas



One-way Translation Based Solution

- Users interact with the High Level, only tools interact with the Low Level representation
- Automatise simple but error-prone tasks
- Prevent misunderstanding due to different languages
- Support specification changes

- specify
- verify
- update

High Level Language

compile

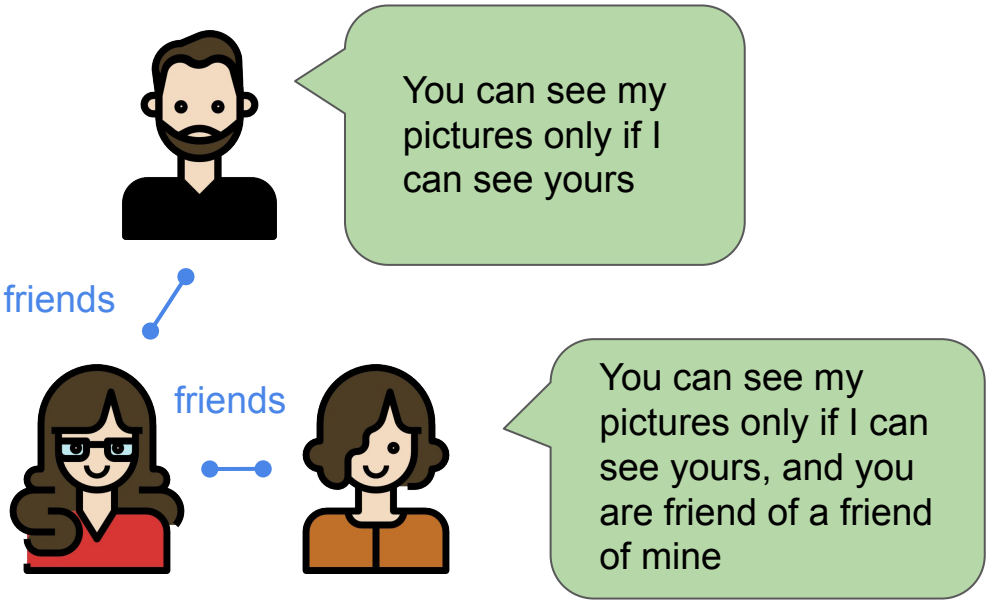
Low Level Language

Collaborative Environments

Users own resources and decide their AC policies

Traditional AC cannot express exchange conditions

New feature: AC decisions based on what the owner gets in return



Resources

Infinite or Reusable

- Private Data on Social Networks
- Files on a File Sharing Platform
- Read-only Accesses

Finite and Not Reusable

- Non Fungible Tokens
- Cryptocurrencies
- Memory Storage
- Computing Power
- Physical Assets

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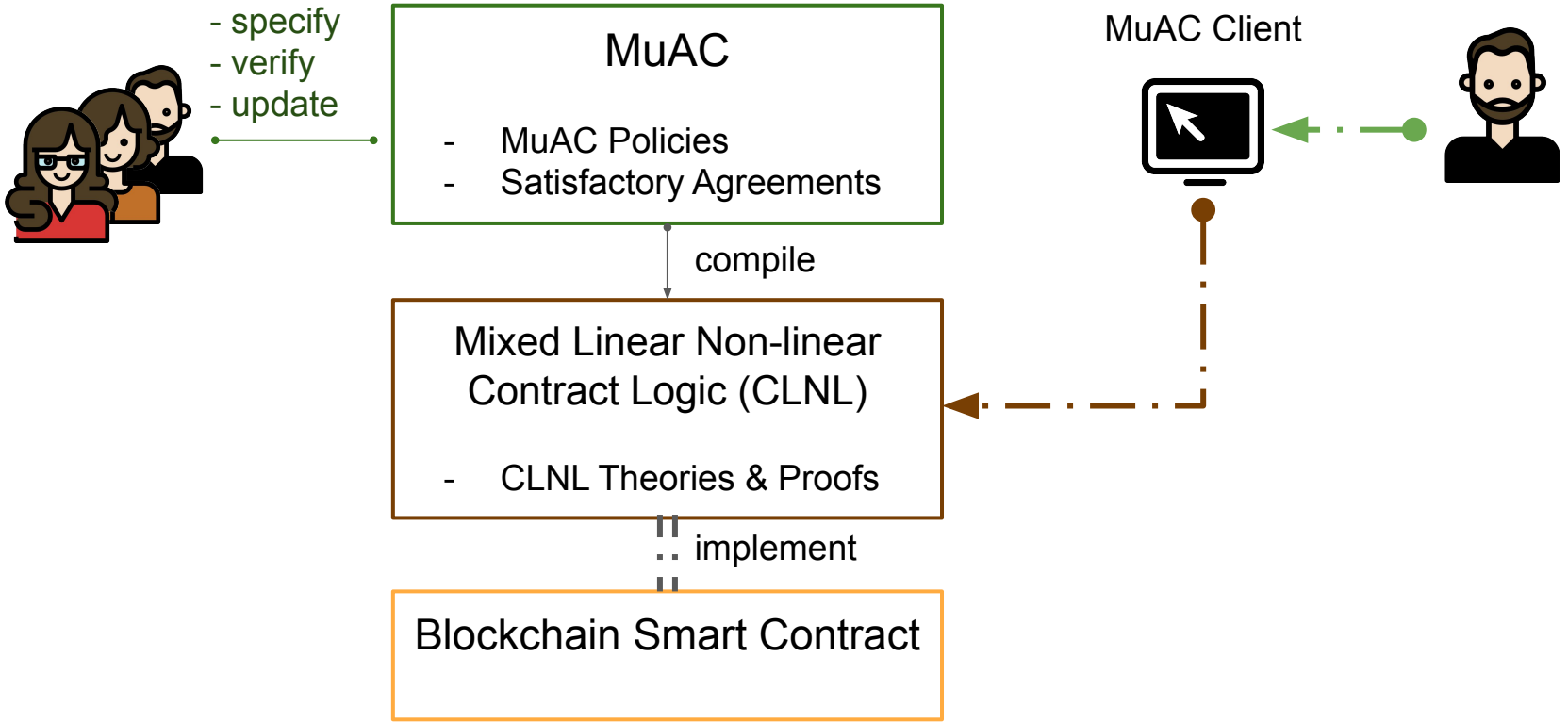
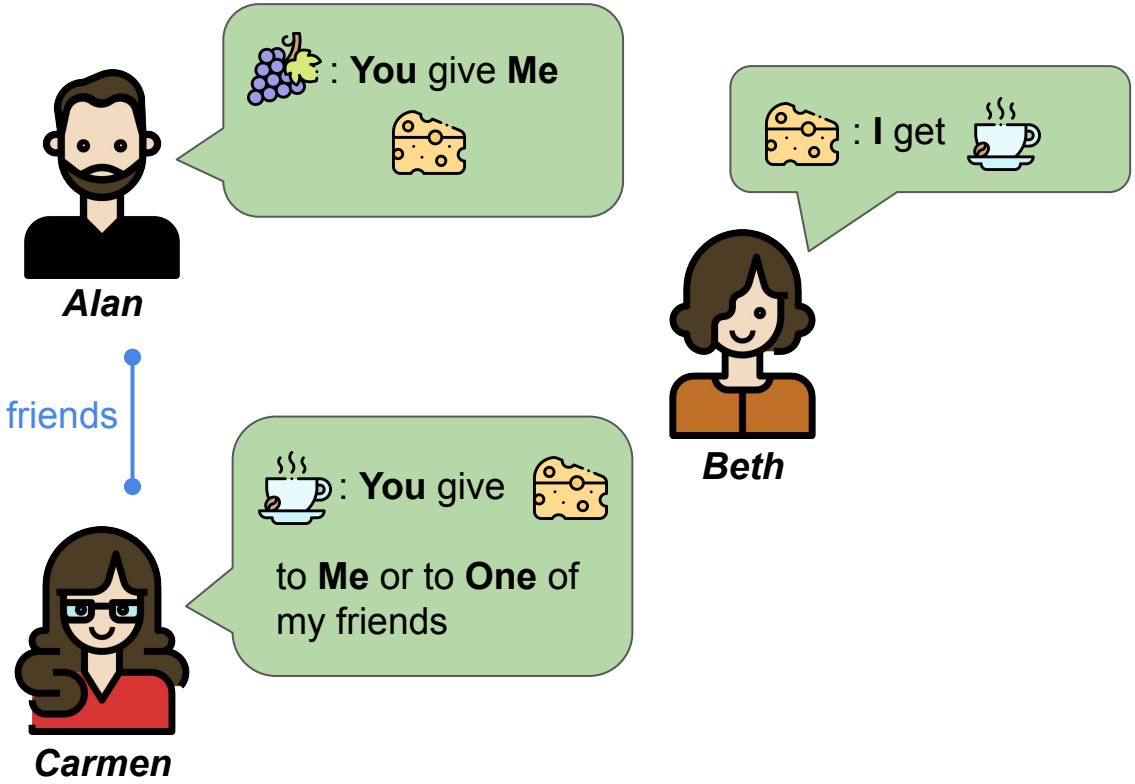
MuAC


- specify
- verify
- update
MuAC
- MuAC Policies
- Satisfactory Agreements
compile
Mixed Linear Non-linear Contract Logic (CLNL)
- CLNL Theories & Proofs
implement
Blockchain Smart Contract
MuAC Client

MuAC Policies

Users define their policies in isolation.

Conditions about what other users must give in order to obtain the permission for a given resource.



CLNL - Computing Agreements

Alan gives  to **Beth** if **Beth** gives  to **Alan**

Beth gives  to **Alan** if **Alan** gives  to **Beth**

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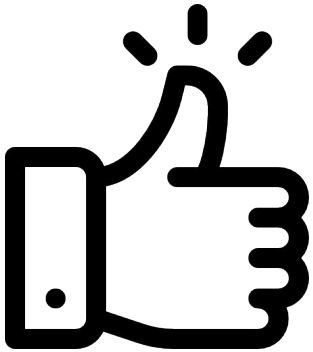

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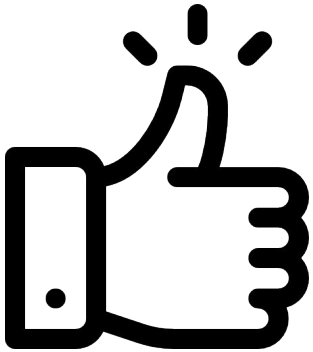
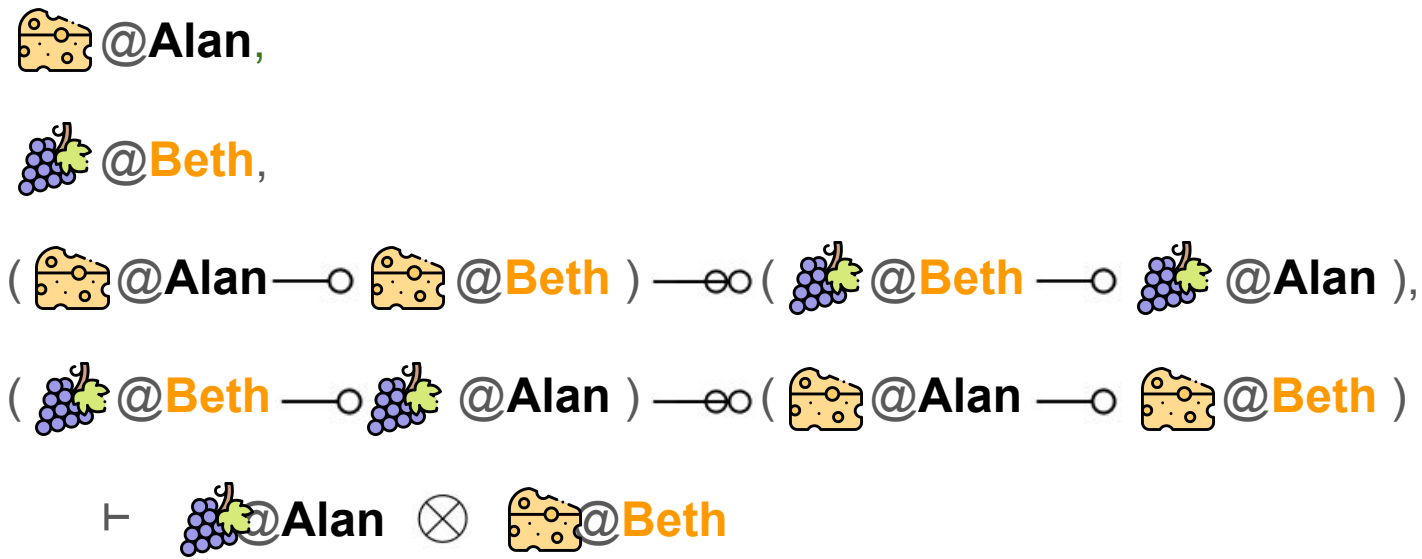


Classical Logic Does not Work!

$$a \Rightarrow b,\ b \Rightarrow a \not\vdash a \wedge b$$

CLNL - Computing Agreements



CLNL - Computing Agreements

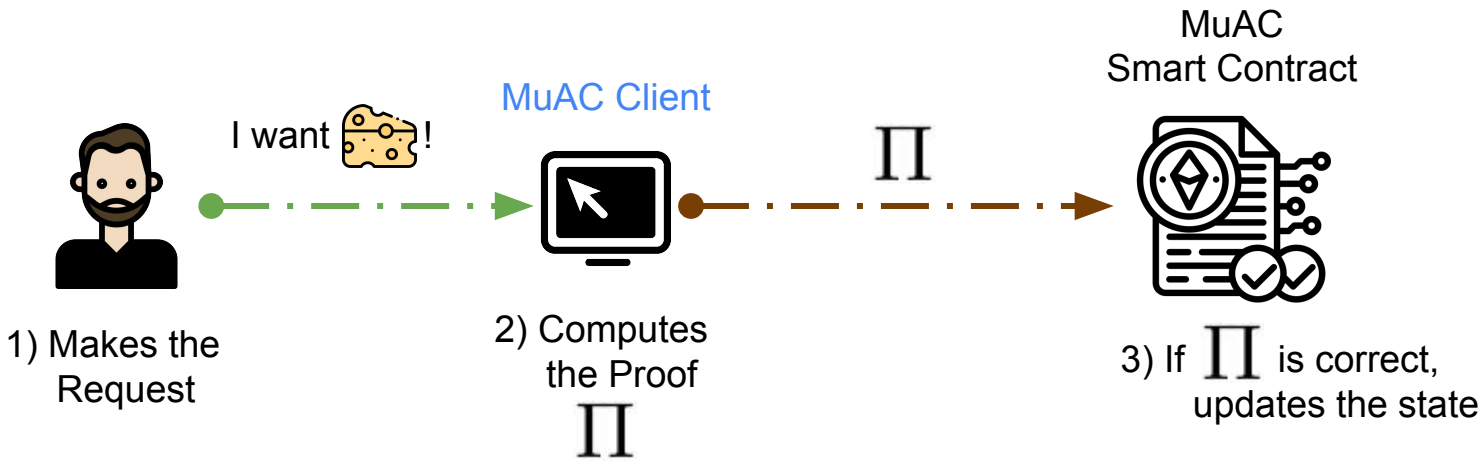
Assuming a request from **Beth** for 

An agreement is mutually satisfactory **iff** a CLNL proof exists

[[Policies]], [[Actual State]] ⊢ [[New State (where **Beth** has ]]

Algorithm for finding such a proof (on a computational fragment)

MuAC as a Smart Contract for Exchanging NFTs



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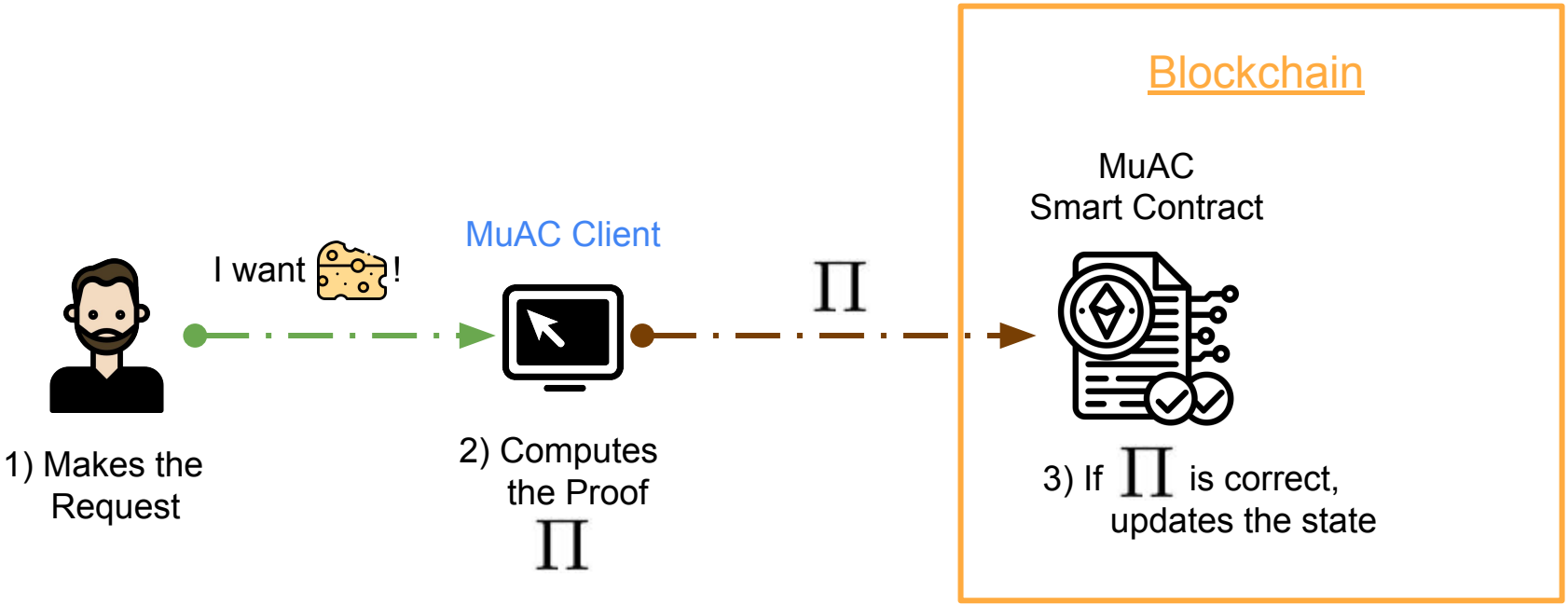

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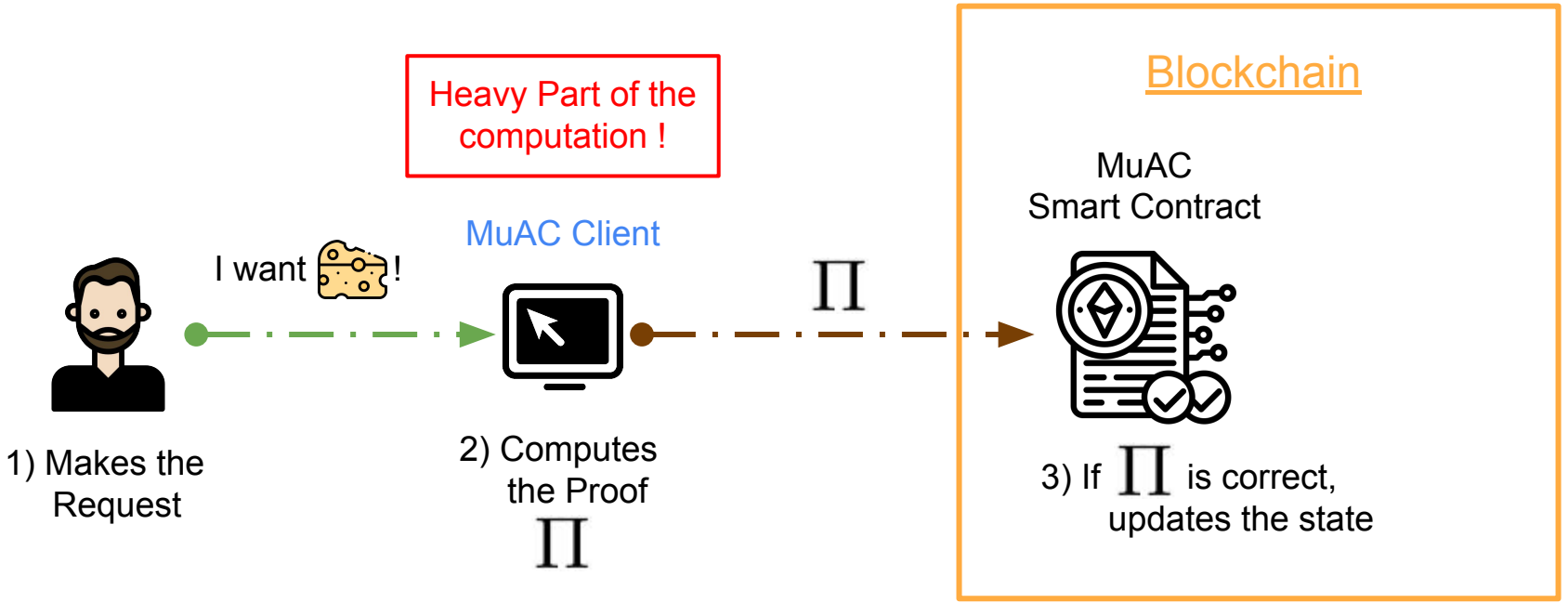
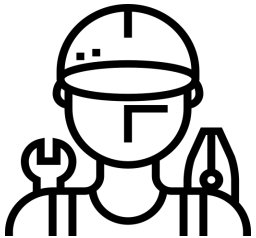


Concluding Remarks - Two-Layers Approach…

High Level



Low Level

Granting Coherence

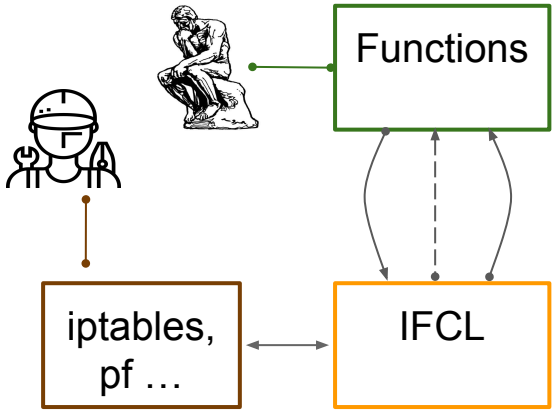
Translation Based

- **one-way** : low level details in charge of tools
- **two-way** : low level details in charge of both humans and tools

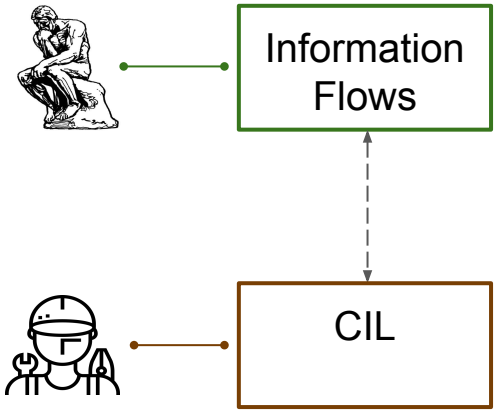
Verification Based :
low level details in charge of humans

…Three Solutions for Three Contexts

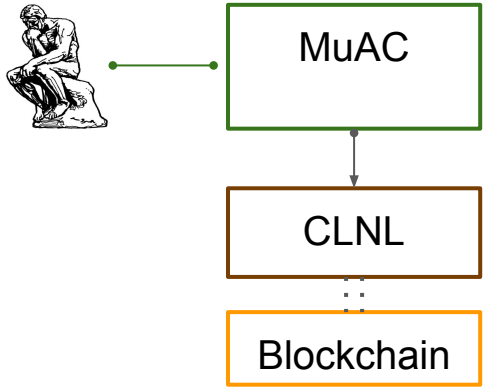
Network Security
Firewalls



System Security
SELinux



Collaborative Environments
Access Grants
Exchanges



Publications

- L. Ceragioli, L. Galletta, M. Tempesta, **From Firewalls to Functions and Back**, *ITASEC 2019*
- L. Ceragioli, P. Degano, L. Galletta, **Are All Firewall Systems Equally Powerful?**, *PLAS@CCS 2019*
- L. Ceragioli, P. Degano, L. Galletta, **Checking the Expressivity of Firewall Languages**, *The Art of Modelling Computational Systems 2019 - LNCS11760*
- C. Bodei, L. Ceragioli, P. Degano, R. Focardi, L. Galletta, F. Luccio, M. Tempesta, L. Veronese, **FWS: Analyzing, Maintaining and Transcompiling Firewalls,** *Journal of Computer Security 29(1) - 2021*

Publications

- L. Ceragioli, P. Degano, L. Galletta, **MuAC: Access Control Language for Mutual Benefits**, *ITASEC 2020*
- L. Ceragioli, P. Degano, L. Galletta, **Can my Firewall System Enforce this Policy?**, *Computers & Security 117 2022*
- L. Ceragioli, L. Galletta, P. Degano, D. Basin, **IFCIL: An Information Flow Configuration Language for SELinux**, *CSF 2022* – `submitted`

Future Work - Extending our Proposals

- Networks
  - Networks with multiple Firewalls
  - Software Defined Networks
- Systems
  - Other CIL features (Roles, MLS)
  - Combination of policies written in different languages
- Collaborative Environments
  - Numbered Resources (currencies)
  - Negative Conditions (conflict of interest)

Future Work - Incrementality and Compositionality

- Translation based solutions
  - Preserve low-level details when compiling
- Verification based solutions
  - Modules related information flows
  - Instant feedback on requirements violations while writing code