AURA: A programming language for authorization and audit

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ICFP
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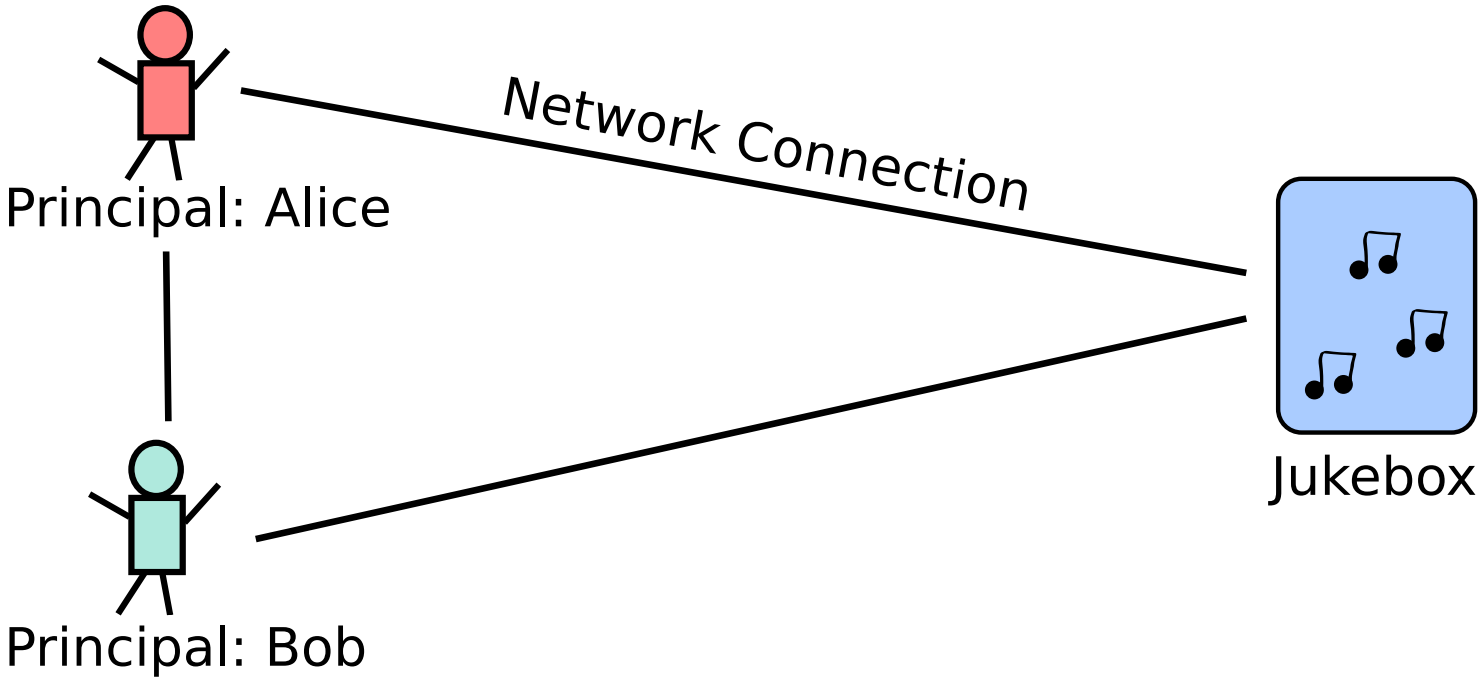
PENN PL

A distributed access control example



Jukebox's signature:

playFor_raw: (s: Song) → (p: **prin**) → Unit

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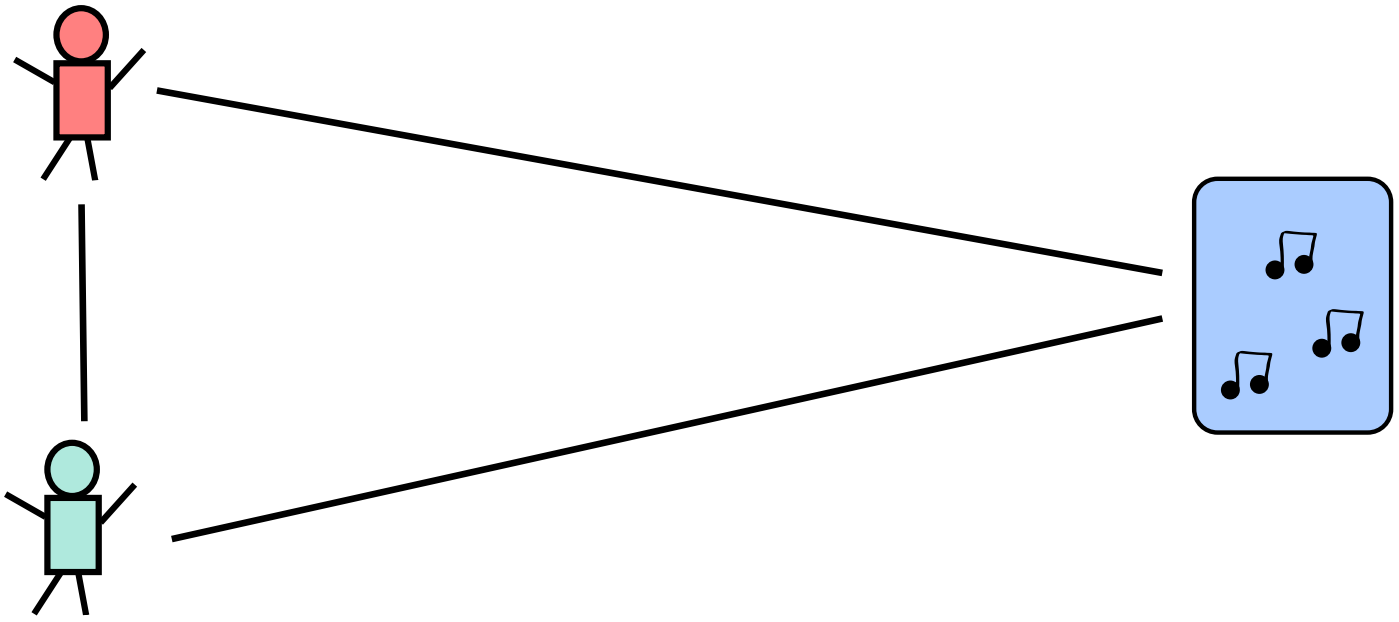

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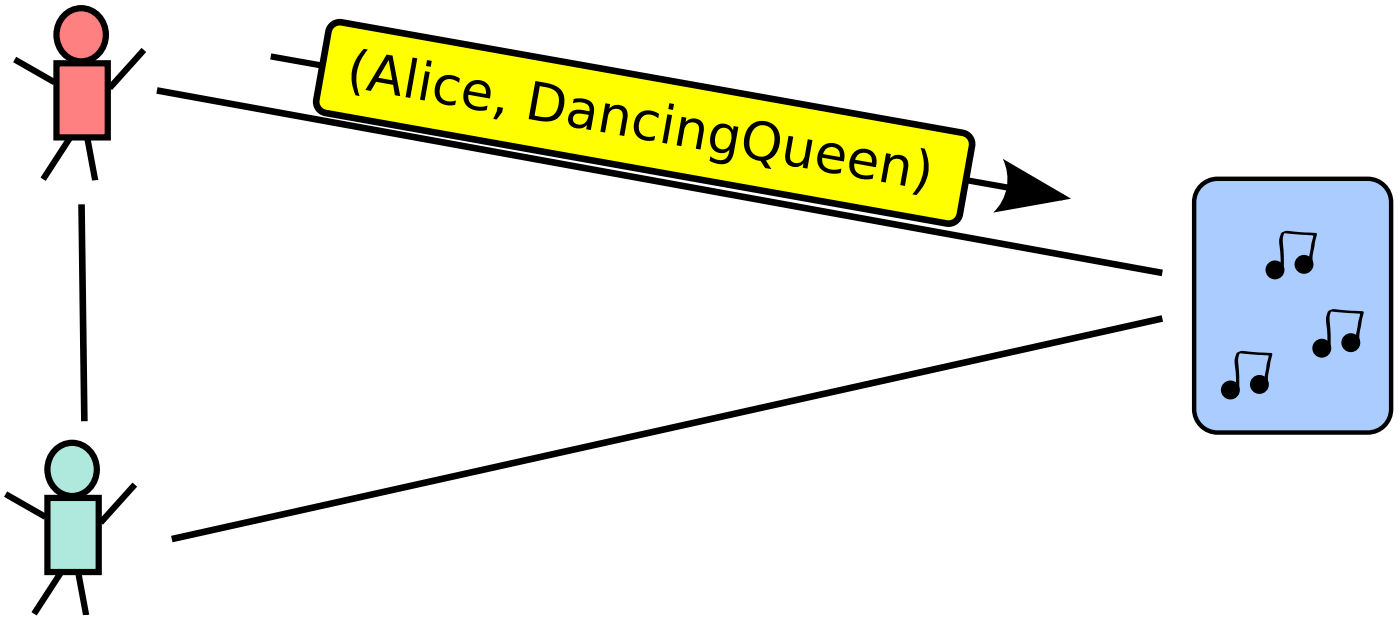

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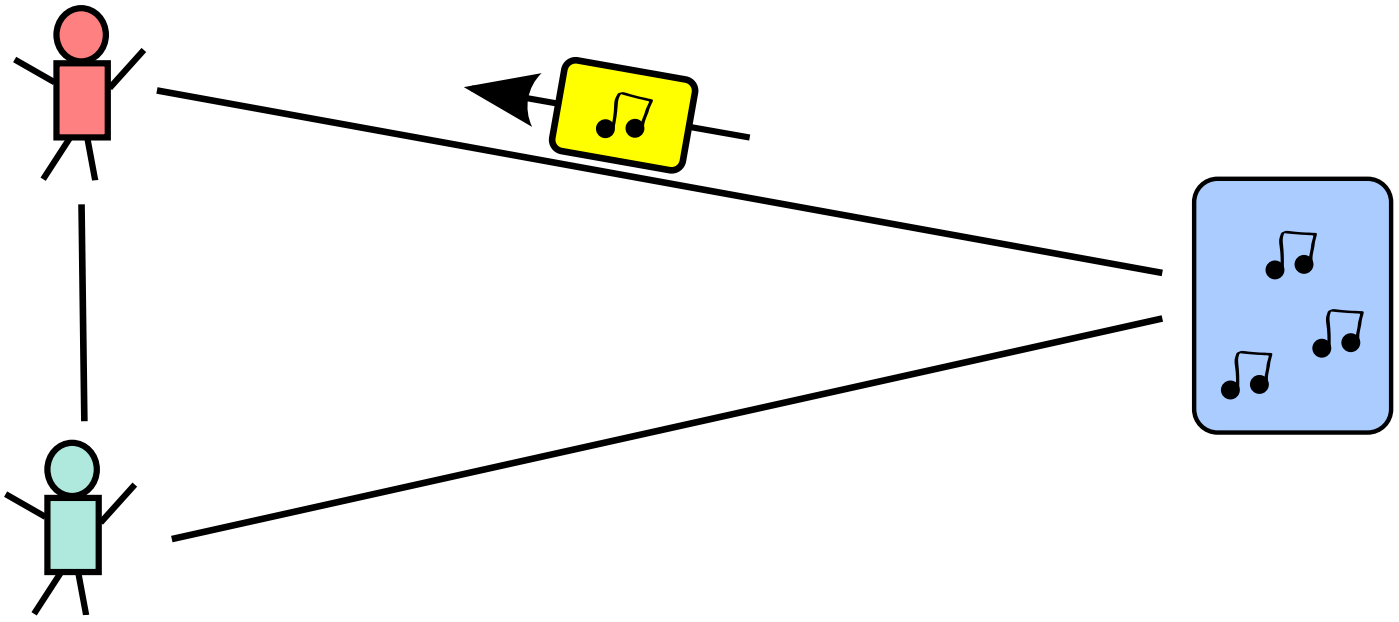

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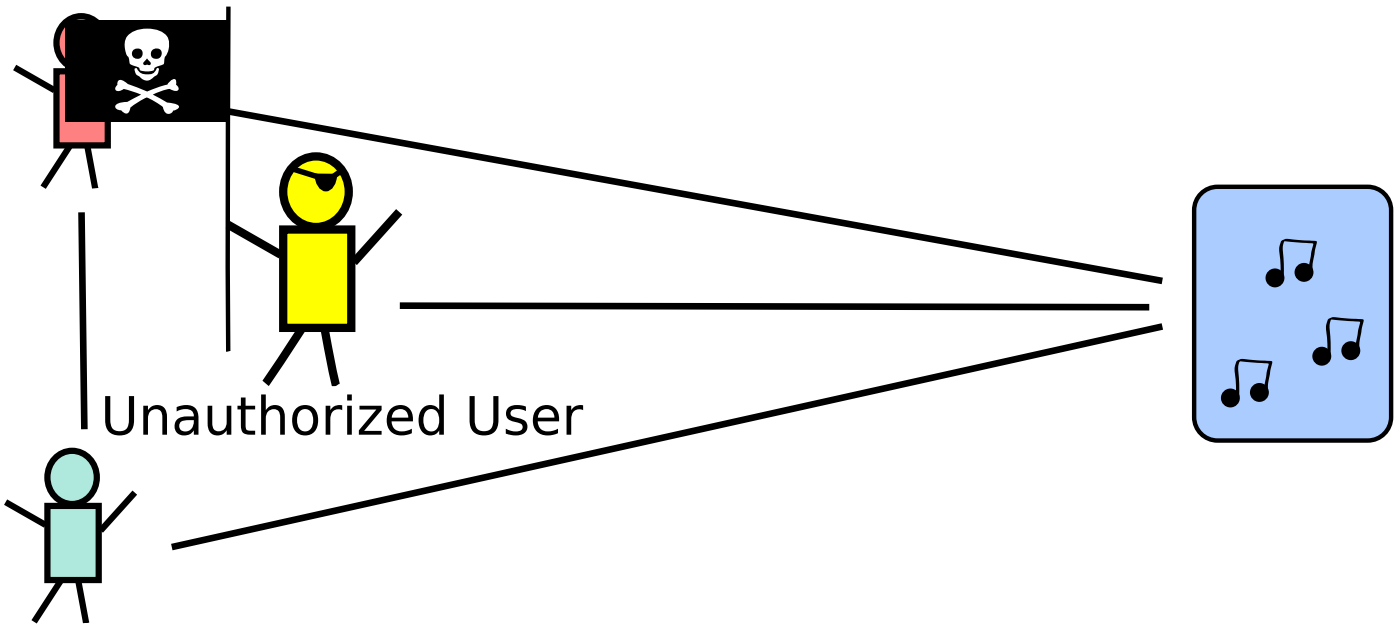

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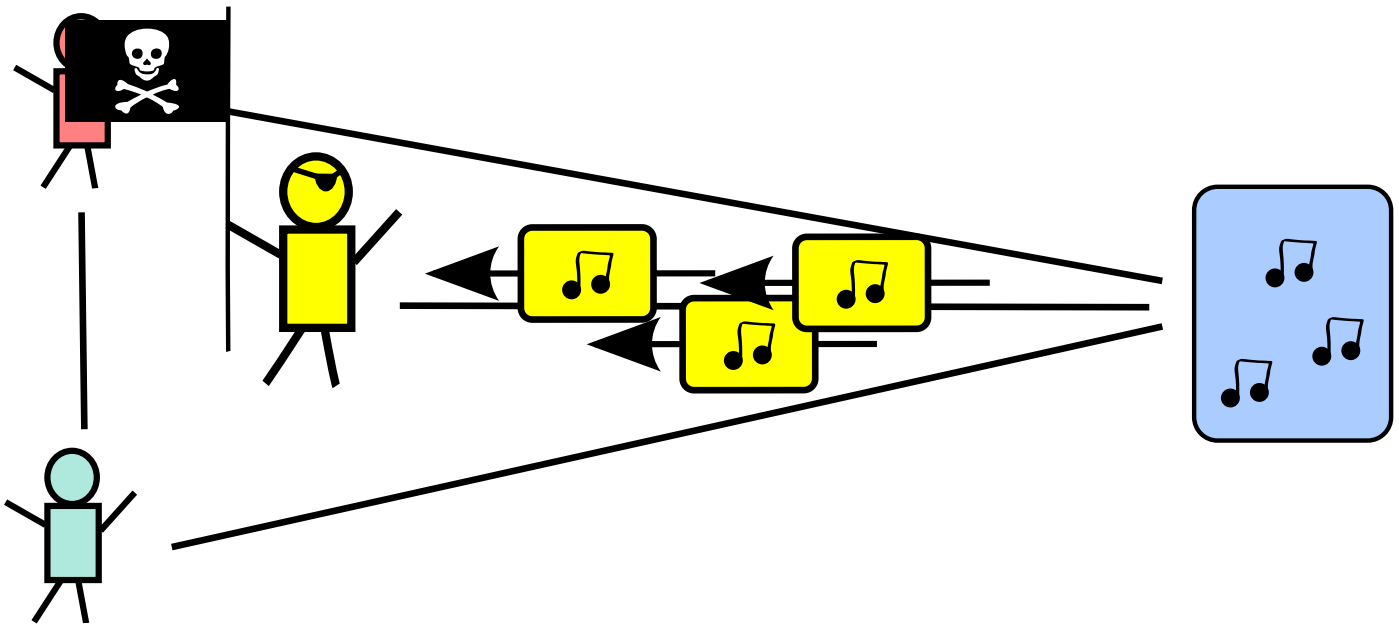

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International Cartel for Fonograph Players Policy

Policy Statement (Simple):

- Songs have one or more owners.
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Policy Enforcement Problems (Hard):

- distributed decision making
- mutual distrust
- prominent use of delegation

AURA: Enforce policy with proof carrying access control.

- Programs build *proofs* attesting to their access rights.
- Proof components
  - standard rules of inference
  - *evidence* capturing principal intent (e.g. signatures)
- AURA runtime:
  - checks proof structure (well-typedness)
  - logs appropriate proofs for later audit

 Proof Carrying Code [Necula+ 98], Grey Project [Bauer+ 05], Protocol Analysis [Fournet+ 07], Evidence-Based Audit [CSF 08]

Encoding policy at the ICFP server

shareRule ≡ **self says** (
(o: **prin**) → (s: Song) → (r: **prin**) →
(Owns o s) →
(o **says** (MayPlay r s)) →
(MayPlay r s)))

playFor: (s: Song) → (p: **prin**) →
pf (**self says** (MayPlay p s)) → Unit

AURA features above: **pf**, **self**, **says**, dependency, effects...

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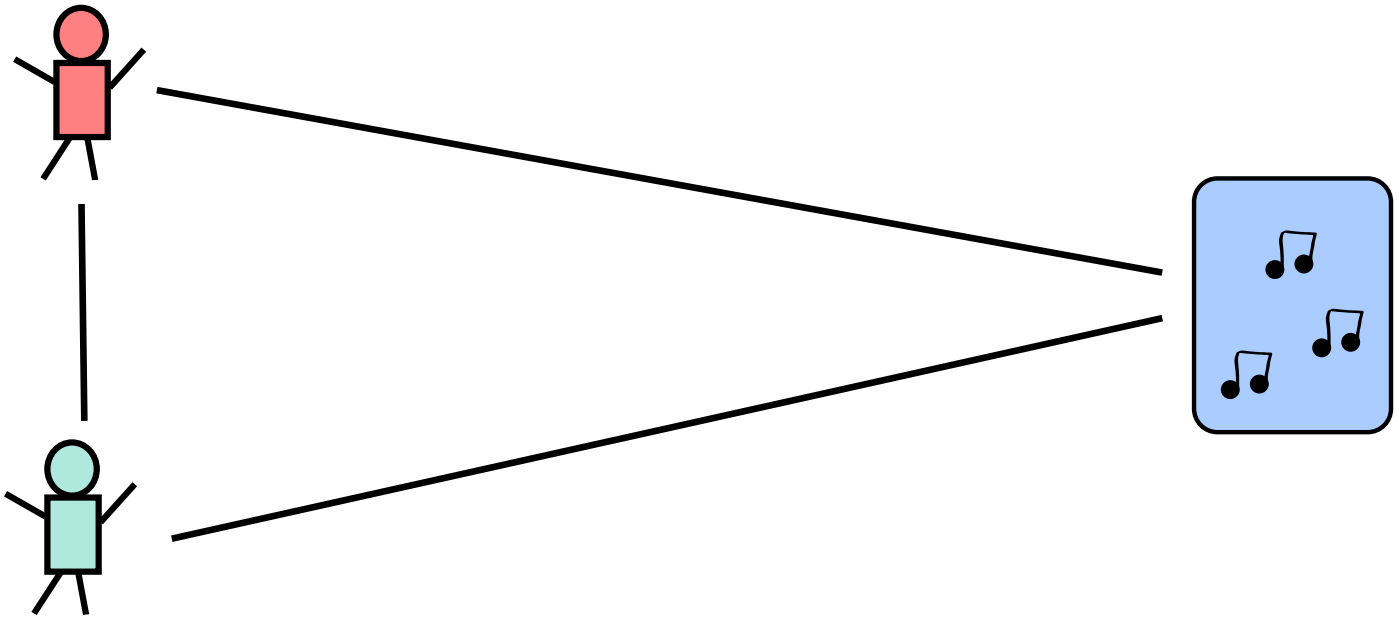
Key Property

A program can only call playFor when it has an appropriate access control proof.

AURA features above: **pf**, **self**, **says**, dependency, effects...

Using the ICFP policy.



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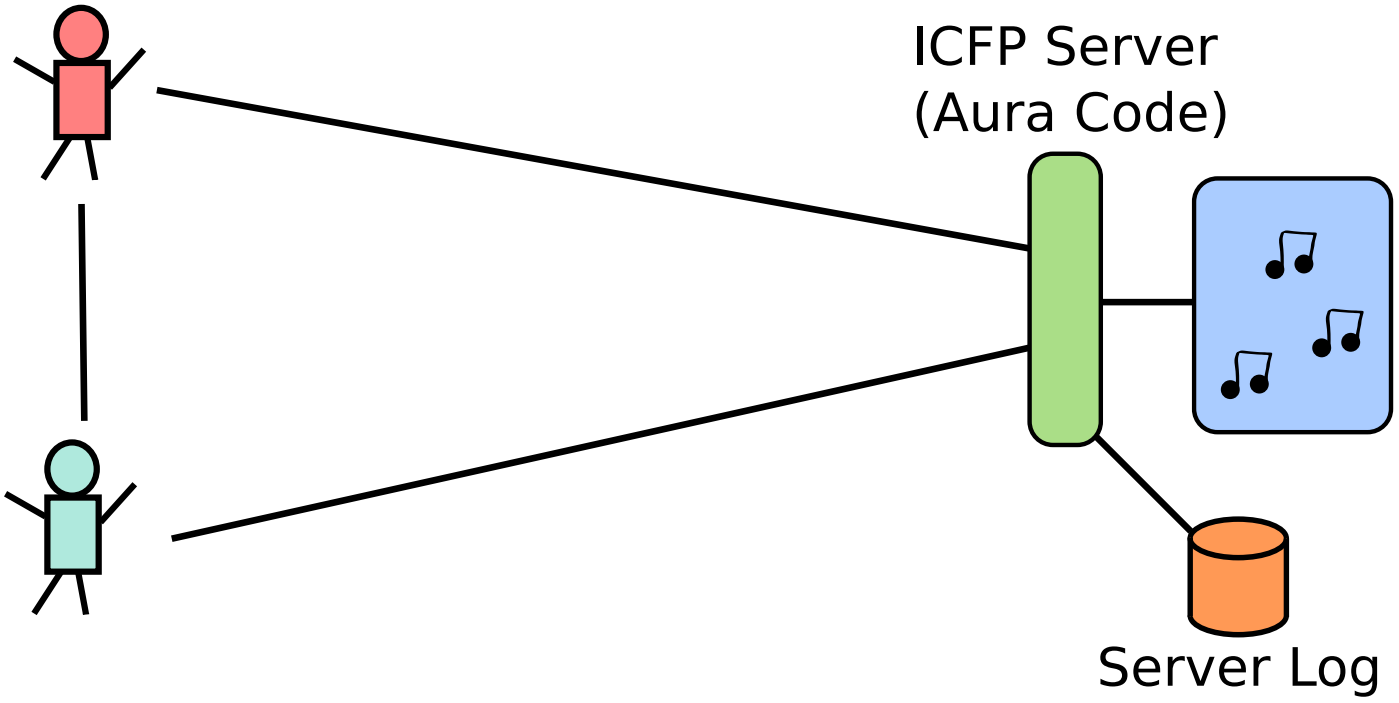

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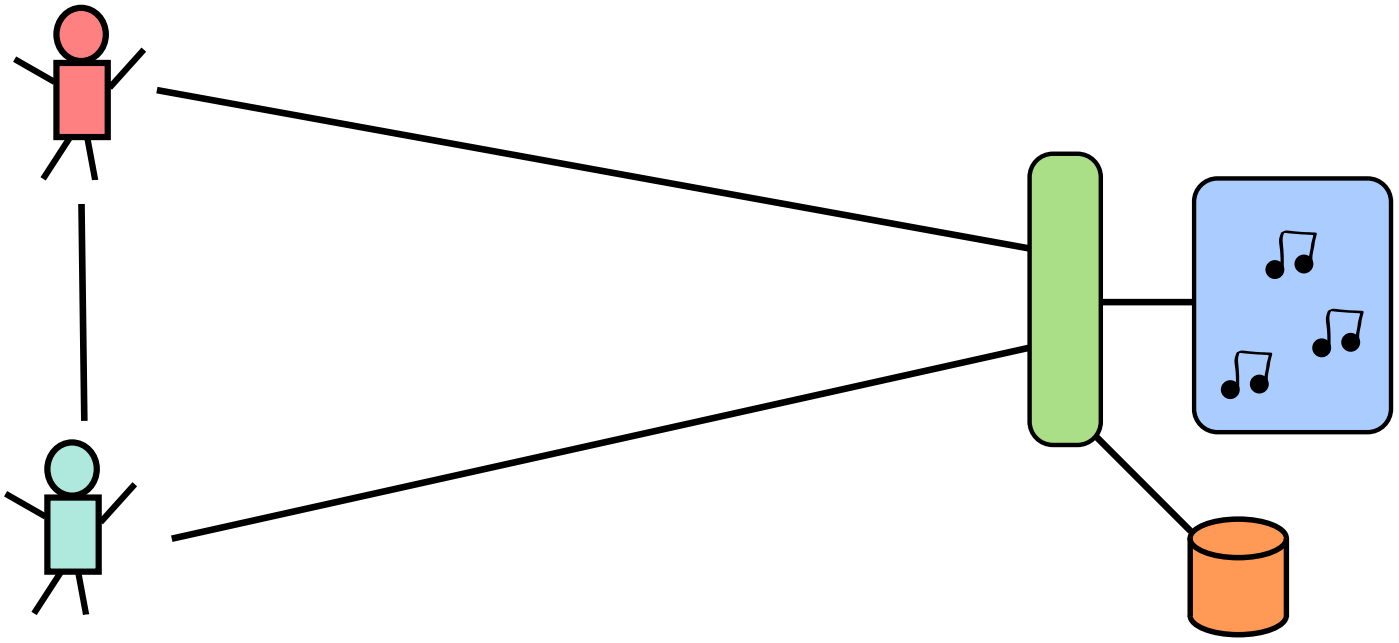

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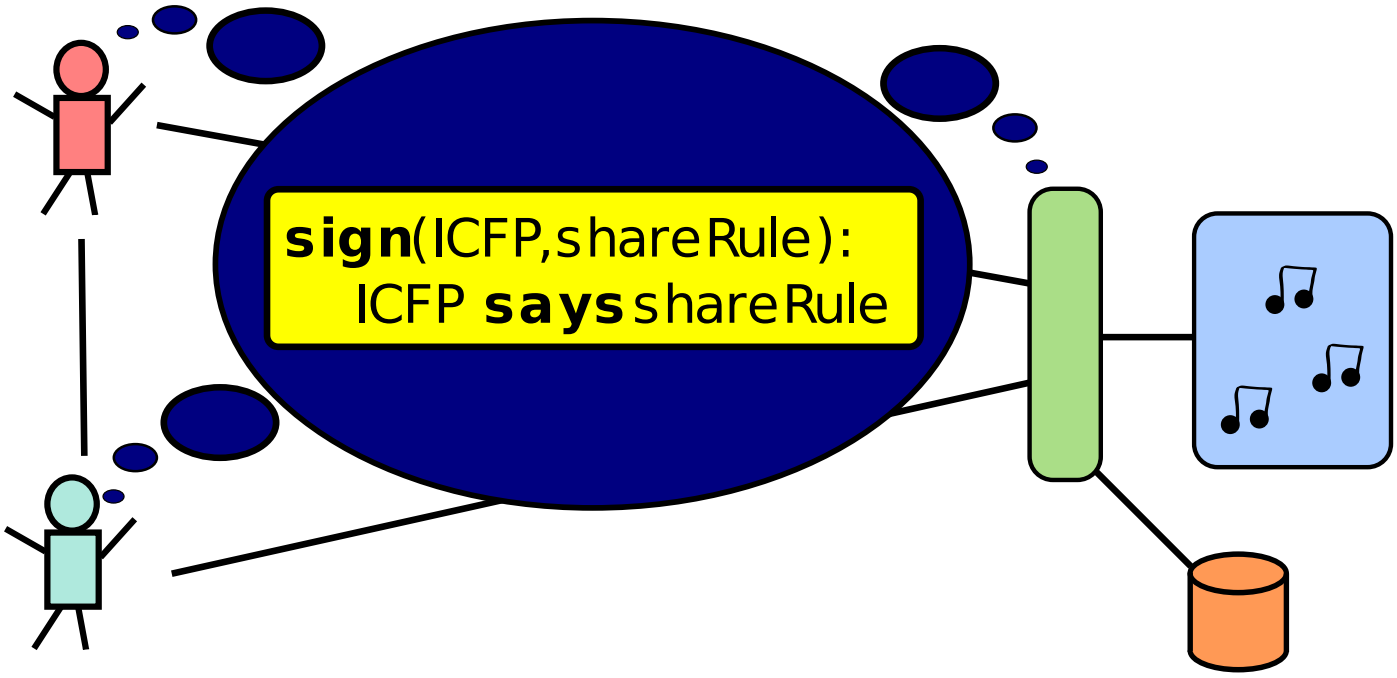

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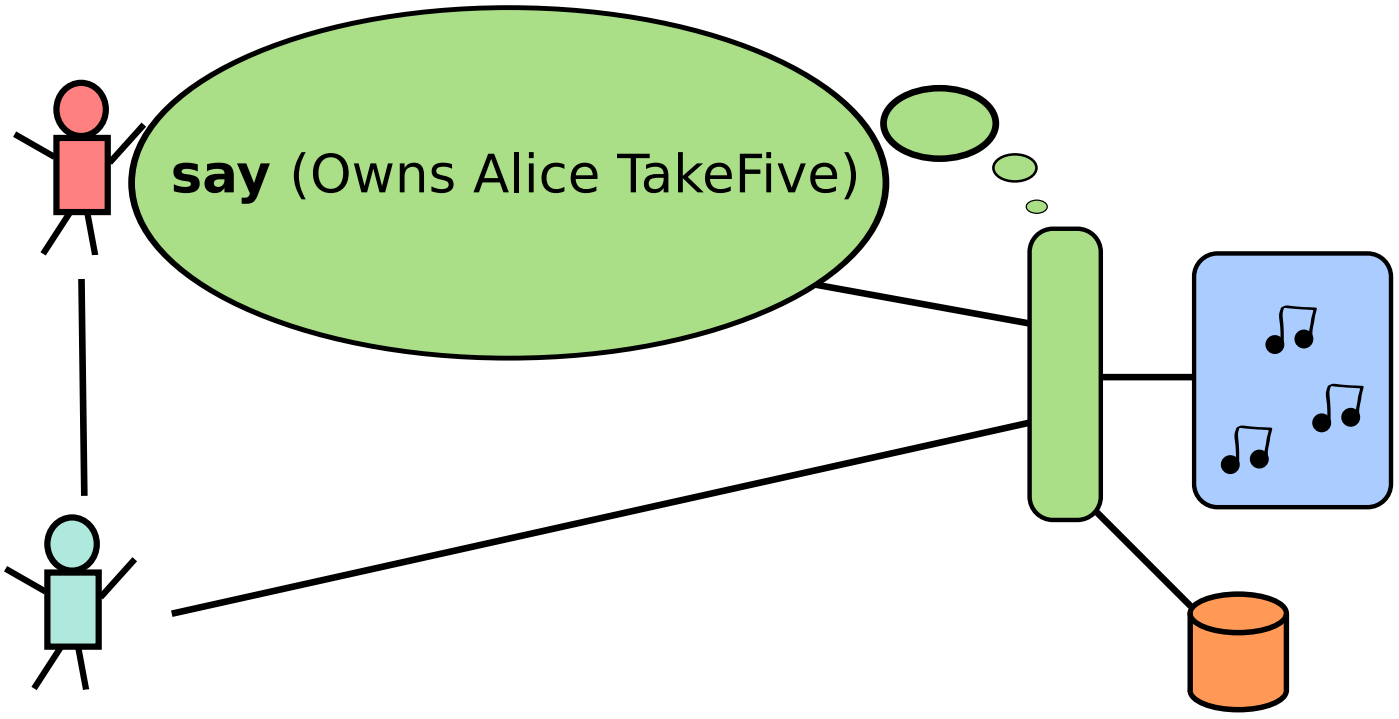

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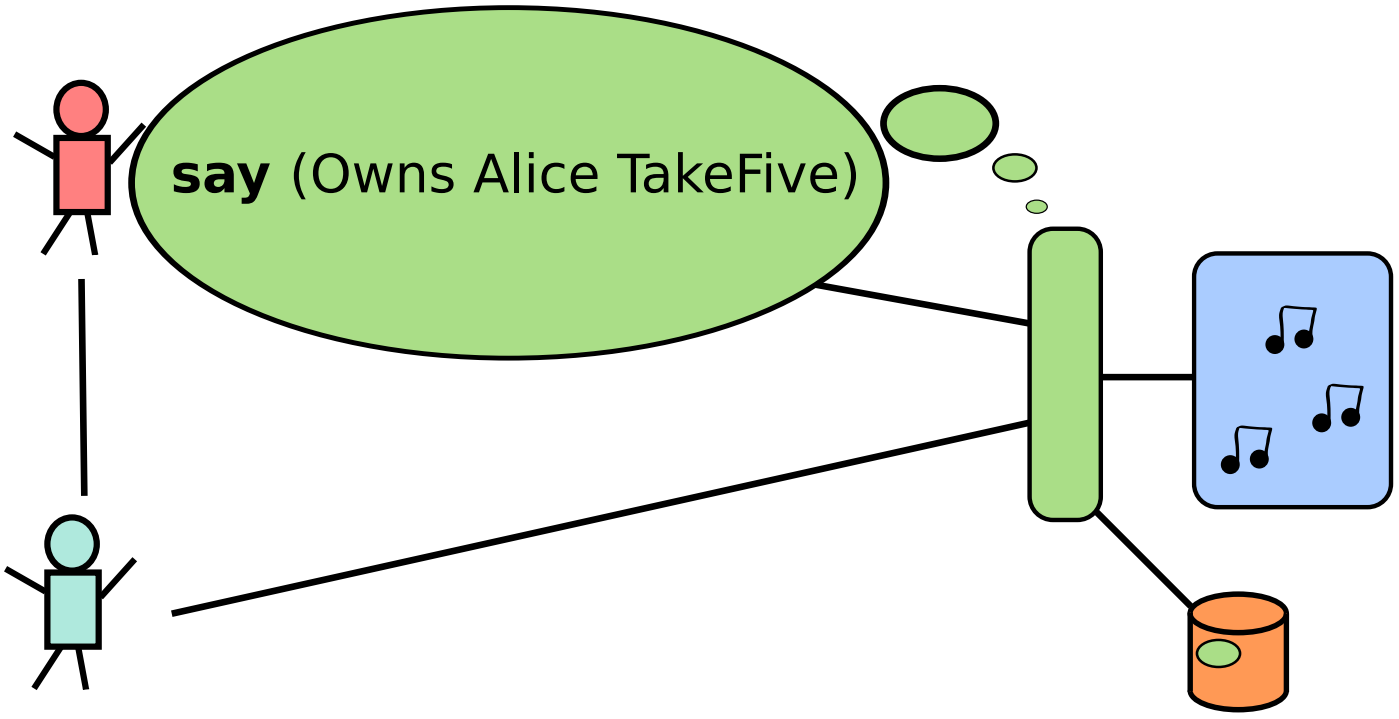

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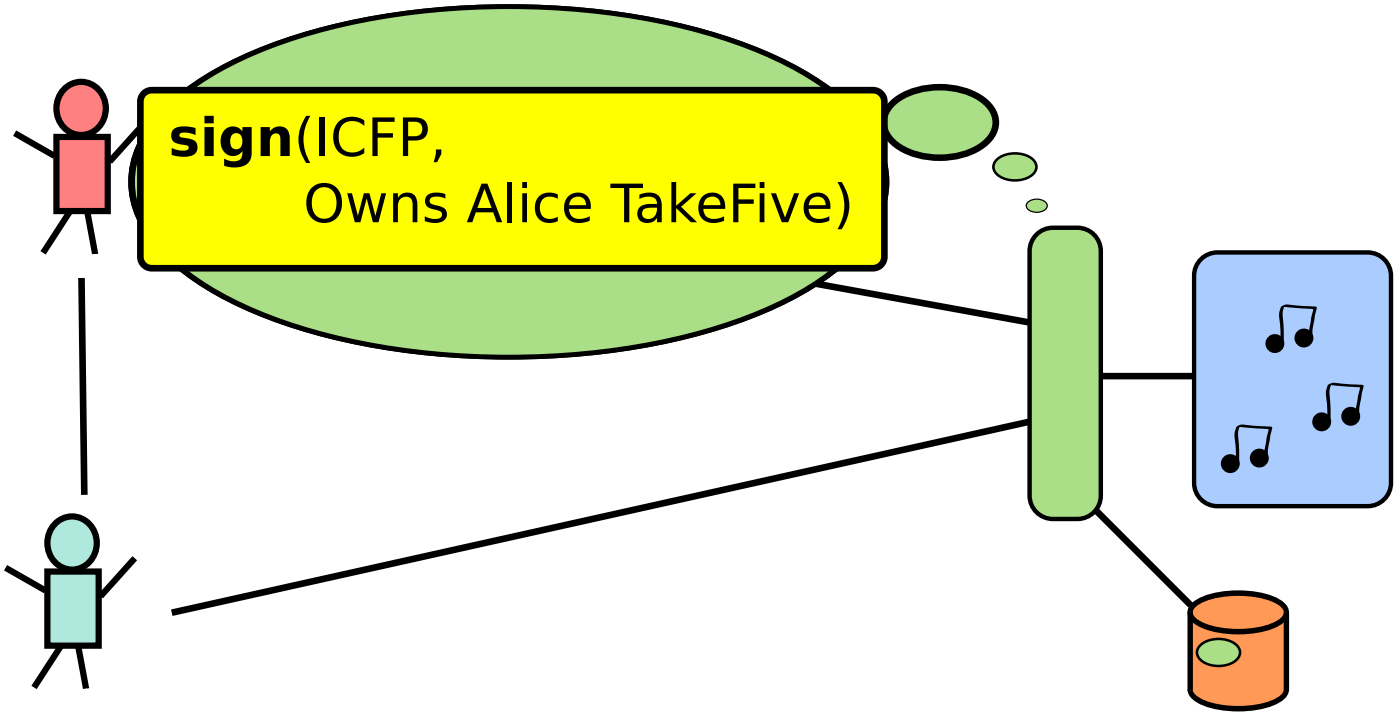

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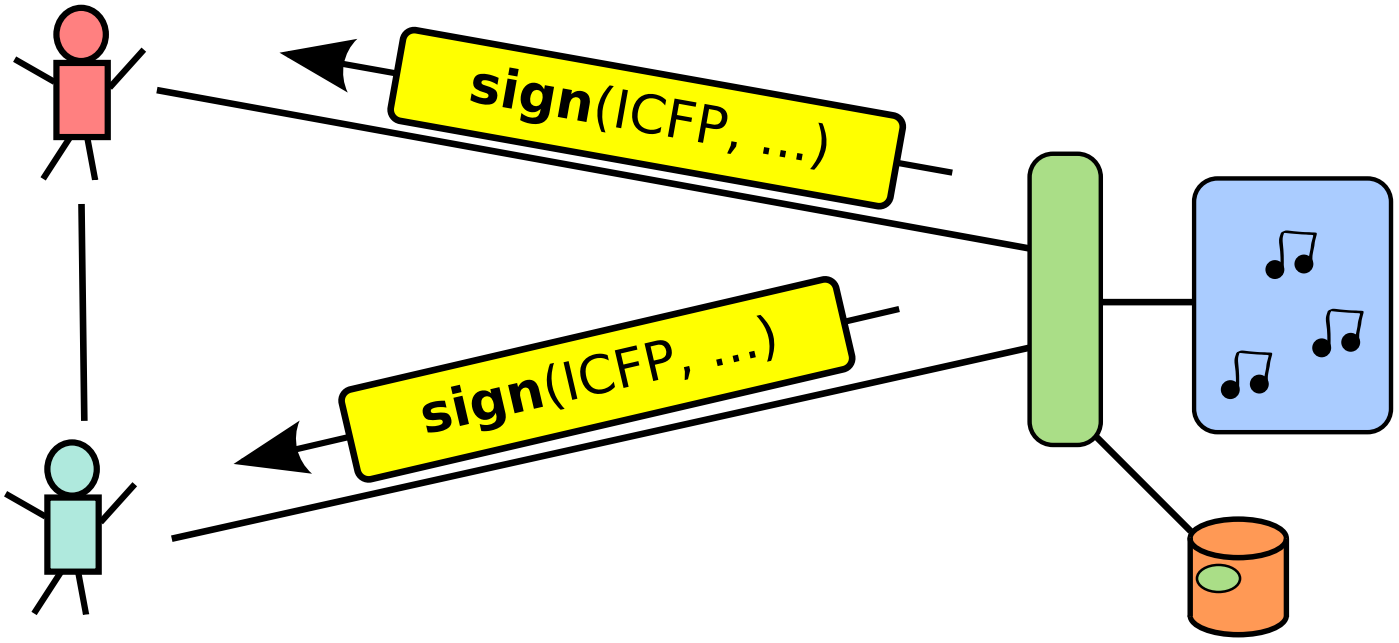

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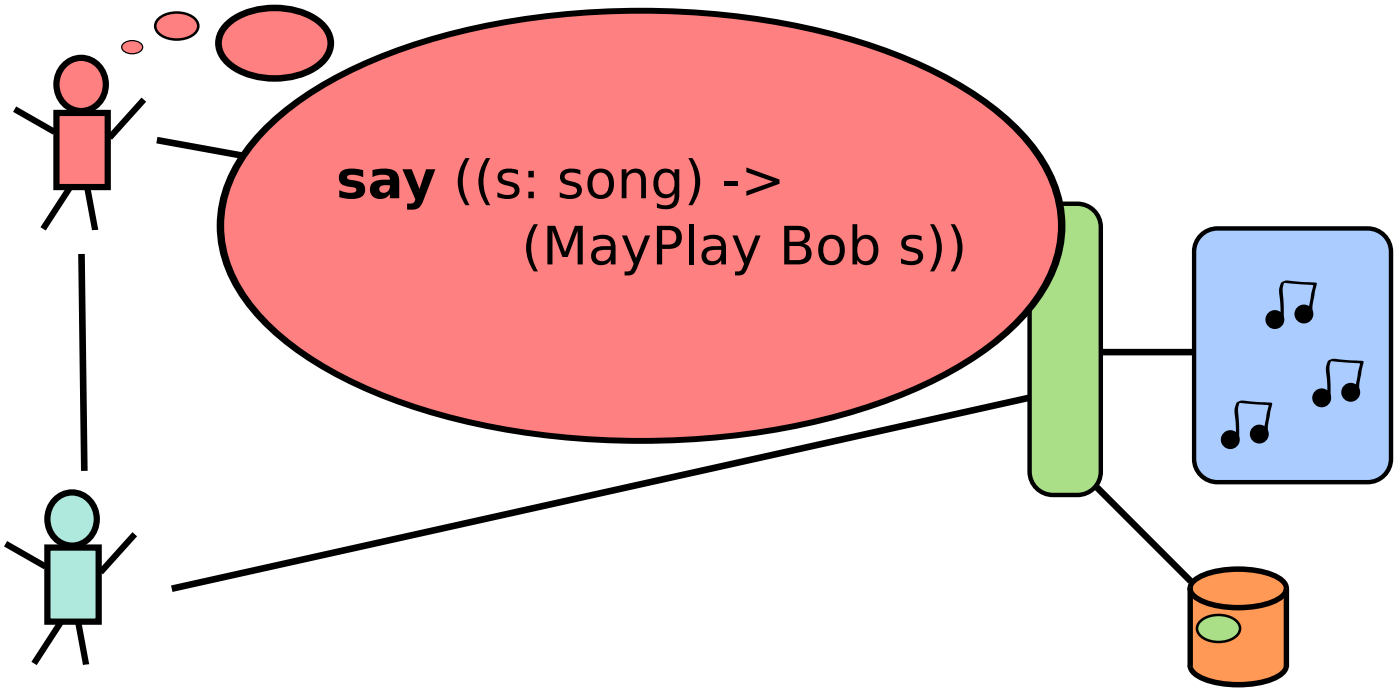

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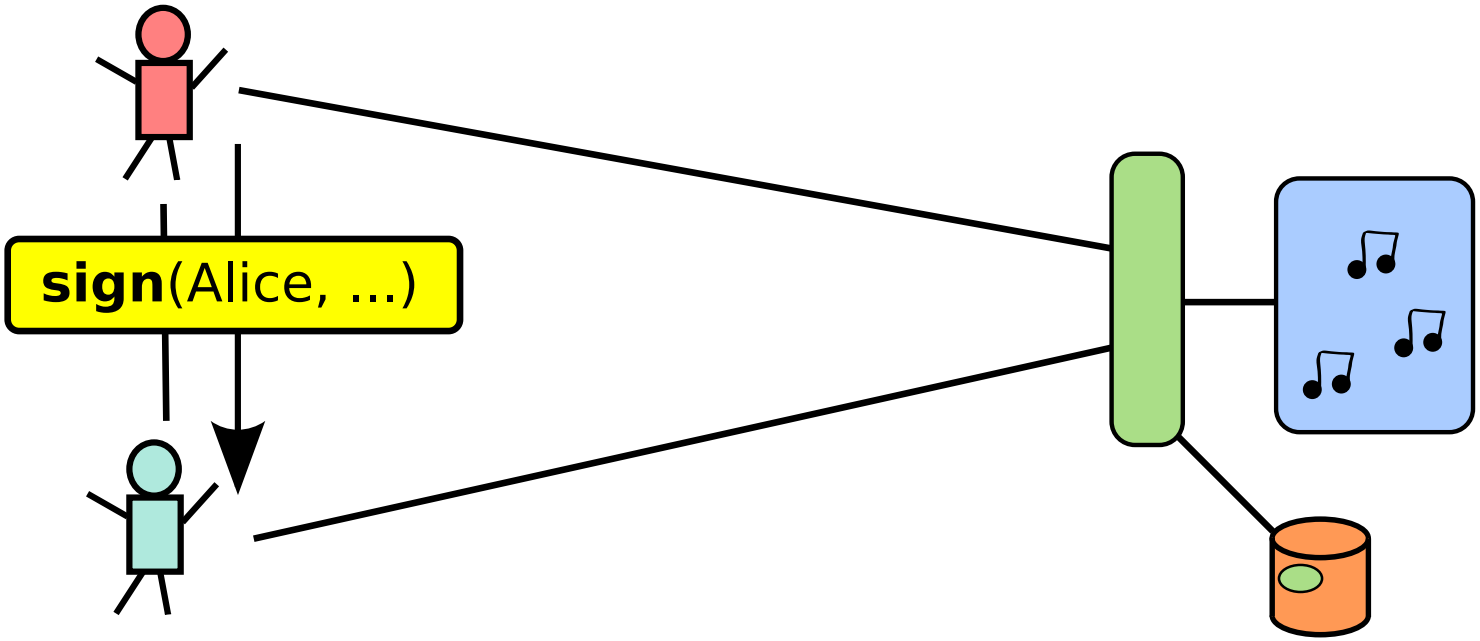

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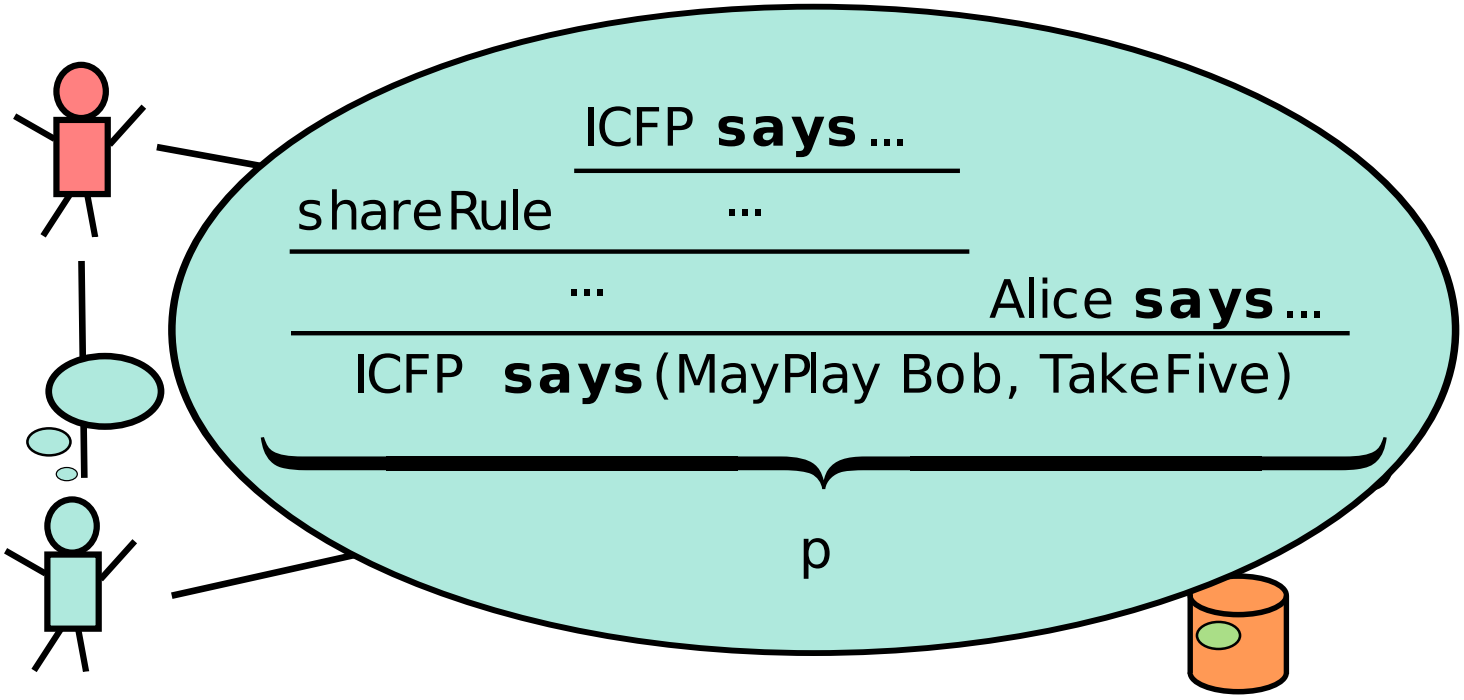

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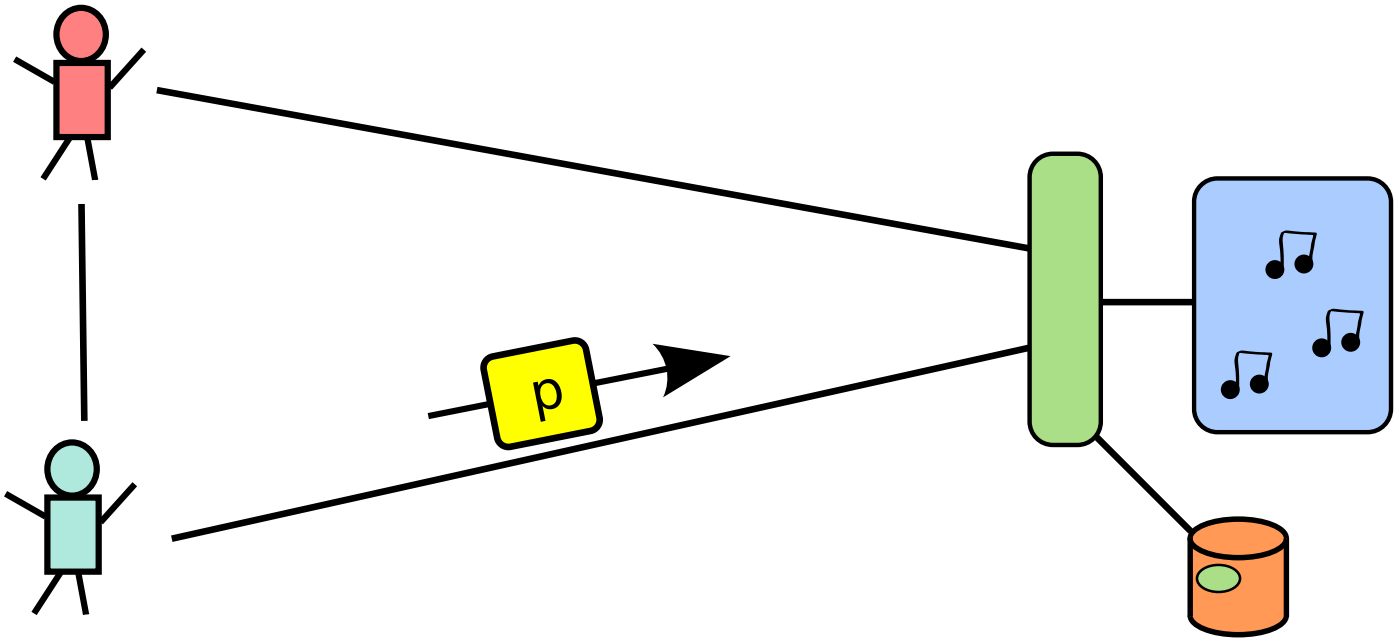

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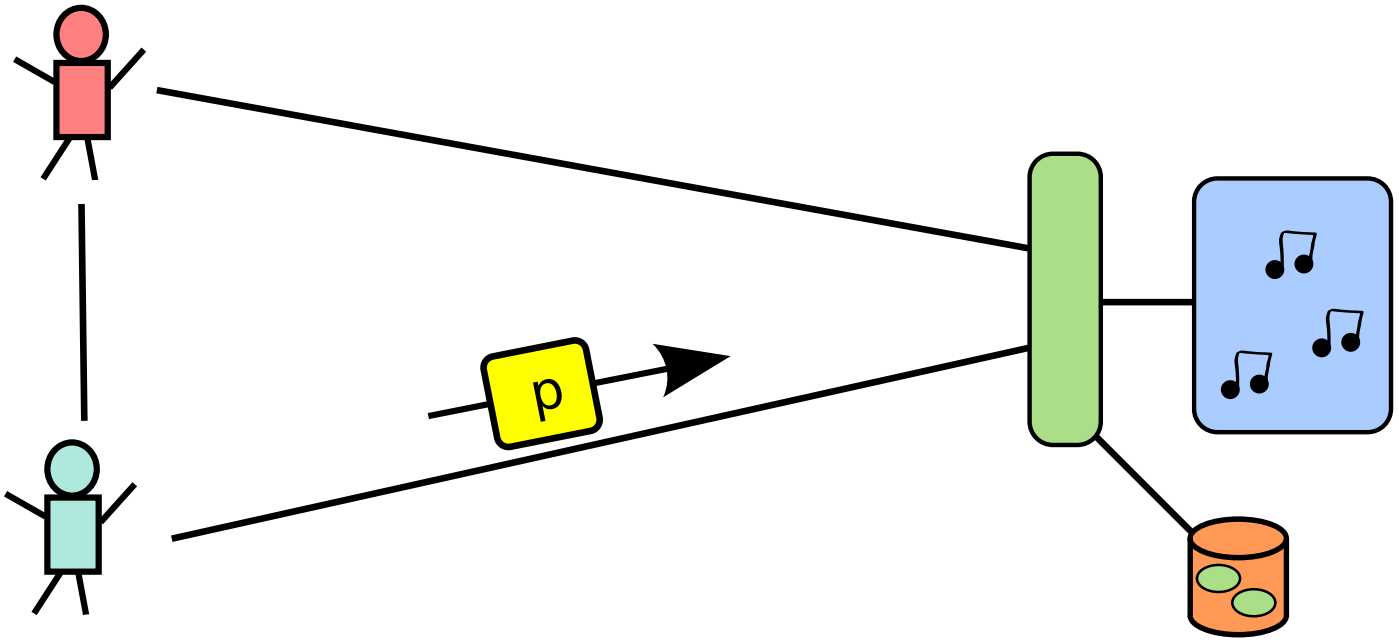

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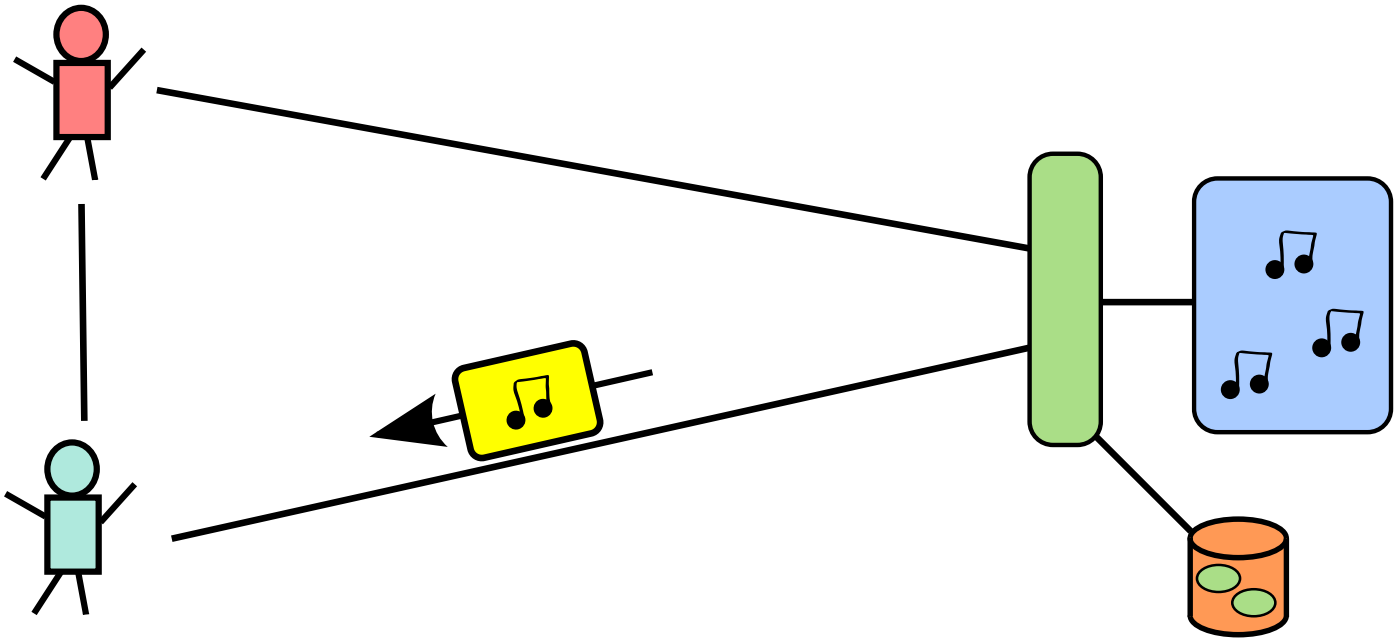

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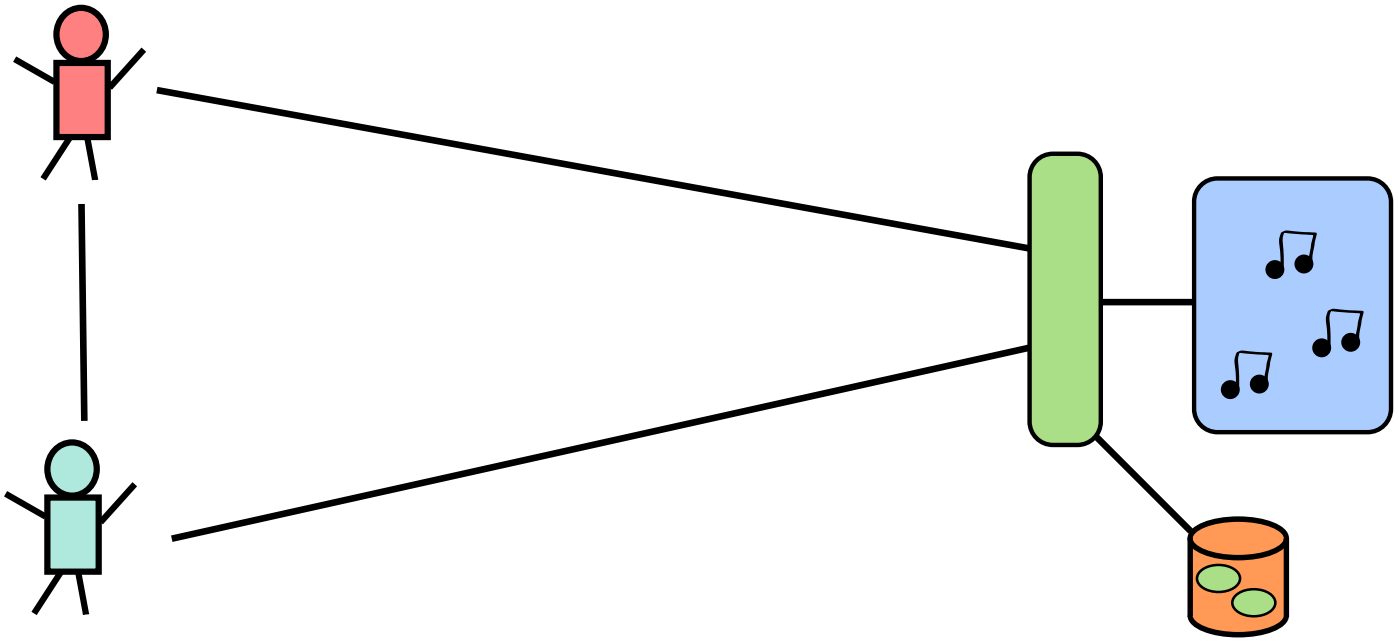

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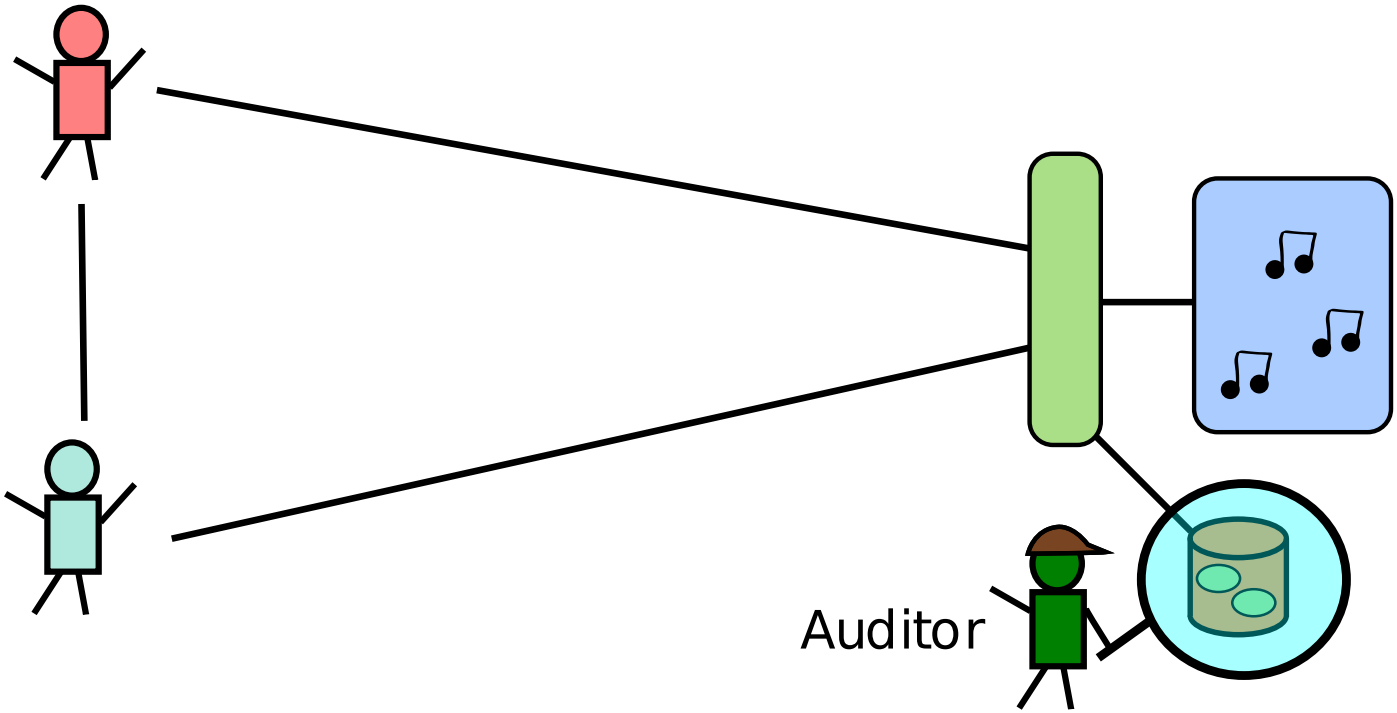

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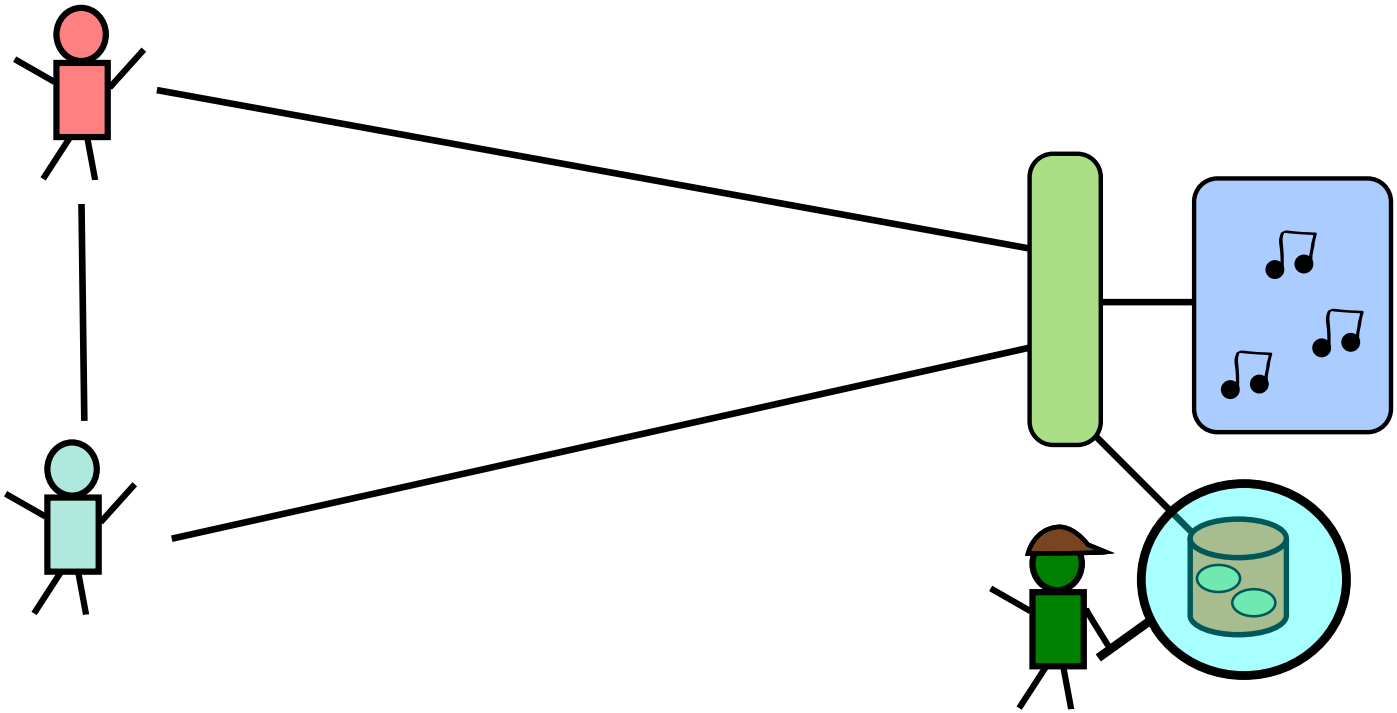

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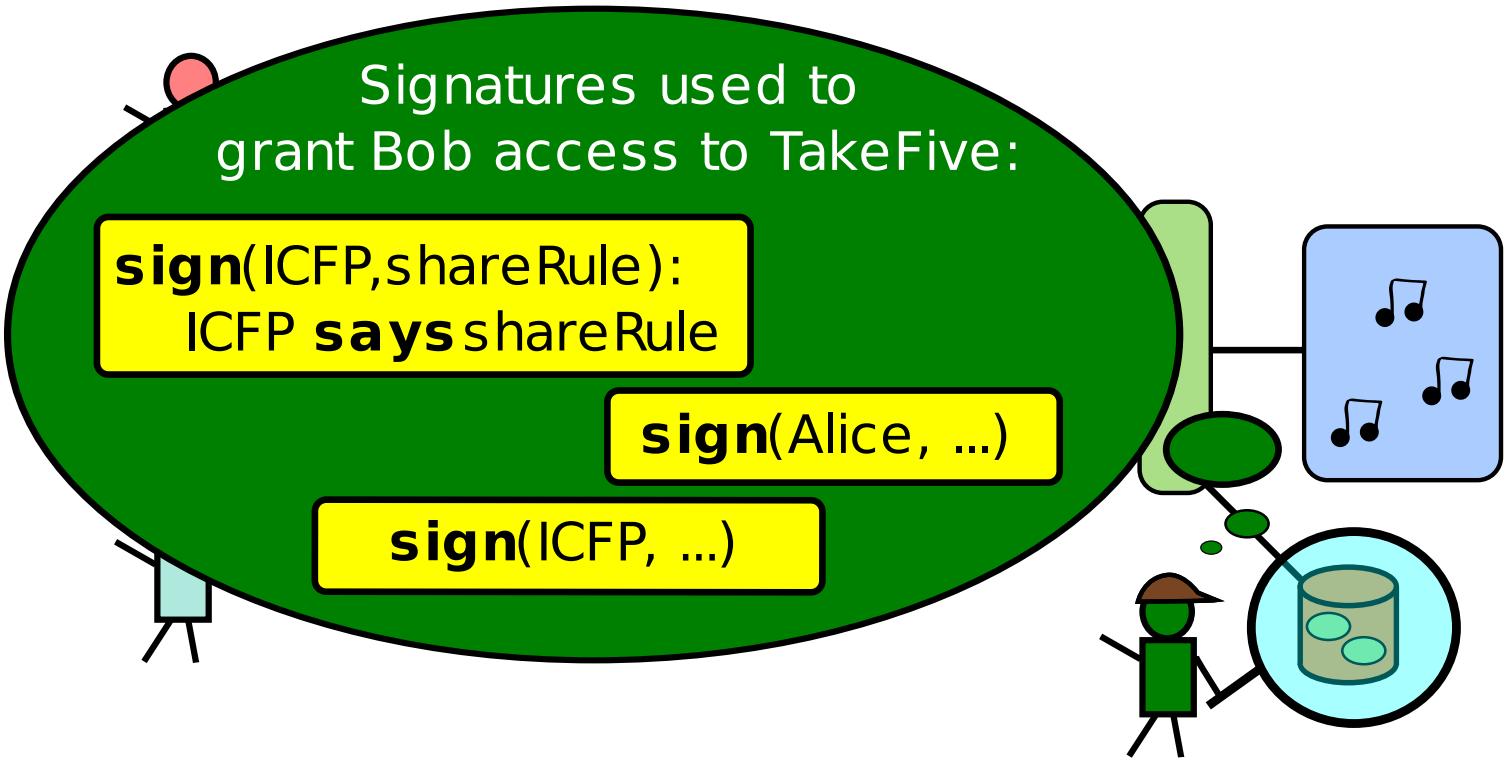
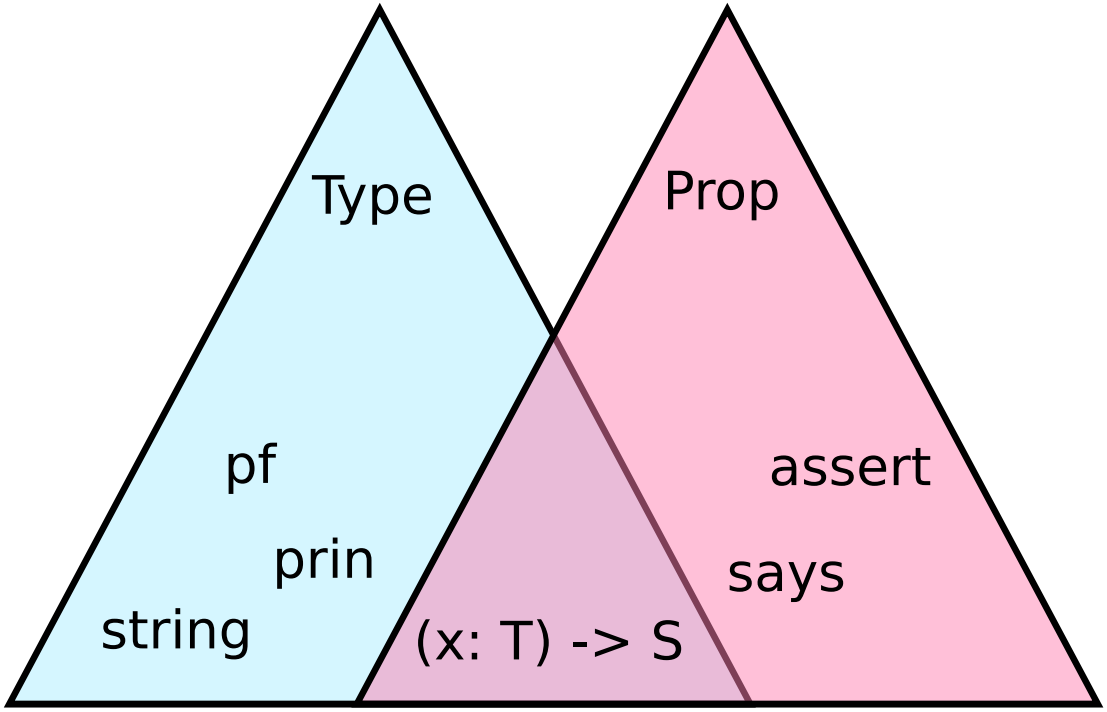


Language Design and Features

AURA's type system is divided into two universes.

Type Contains computation expressions. Includes non-termination and world effects.

Prop Contains pure expressions with a clear interpretation as proofs.



Aura's says modality represents affirmation.

- The proposition "principal Alice affirms proposition P."

  Alice **says** P: **Prop**

- Principals may actively affirm propositions with signatures.

  sign(Alice, P): Alice **says** P

- Principals affirm "true" propositions

  return Alice p: Alice **says** P

  when p: P.

DCC [Abadi+ 06], Logic with Explicit Time [DeYoung+ 08]

Dependent types allow for expressive rules.

Example (Bob acts for Alice)

$$\text{Alice } \textbf{says } ((\text{P: } \textbf{Prop}) \rightarrow \text{Bob } \textbf{says } \text{P} \rightarrow \text{P})$$

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$$\text{Alice } \textbf{says } ((P\colon \textbf{Prop}) \to \text{Bob } \textbf{says } P \to P)$$

Example (Bob acts for Alice only regarding jazz)

$$\begin{aligned}\text{Alice } \textbf{says } ((s\colon \text{Song}) \to \text{isJazz } s \to \\ \text{Bob } \textbf{says } (\text{MayPlay Bob } s) \to \text{MayPlay Bob } s)\end{aligned}$$

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Restricted formulation of dependent types:

- expressive enough for access control
- too weak for general correctness properties
- AURA feels more like ML than Coq

Effect **say** reifies a program's authority as a signature.

- Programs manufacture new **sign** objects with **say**.
- Intuitively **say** uses the program's (e.g. current user's) private key to generate the signature.
- Special principal **self** stands in for the program.

say P: **self says** P

say P $\mapsto$ **sign**(**self**, P)

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say P: **pf**(**self says** P)

say P $\mapsto$ **return**(**sign**(**self**, P))

Technical Point

The **pf** monad protects the **Prop** universe from **say**'s world effect.

AURA contains inductive types and *assertions*.

- Inductive Types define complex data structures.

  data List : **Type** → **Type** {
  | nil : (t :**Type**) → (List t)
  | cons : (t :**Type**) → t → (List t) → (List t) }

- Inductive Props define simple inference systems subject to a (draconian) positivity constraint.

  data And: **Prop** → **Prop** → **Prop** {
  | both: (P: **Prop**) → (Q: **Prop**) → P → Q → And P Q }

  data False: **Prop** { }

- Assertions define access control predicates

  assert Owns: **prin** → Song → **Prop**

Assertion types are uninhabited, but not false.

Inductive types admit pattern matching.

Example

$\lambda f\colon$ Alice **says** False. $\lambda P\colon$ **Prop**. . . .
match f **with** (P) $\{\}$ . . .
$\quad :$ Alice **says** False $\rightarrow$ (P: **Prop**) $\rightarrow$ Alice **says** P

Assertions have no elimination form.

- Intuition: Assertions $\approx$ type variables.
- There is no analogous function of type

ICFP **says** (Owns Bob Thriller) $\rightarrow$
(P:**Prop**) $\rightarrow$ ICFP **says** P.

Theory and Practice

AURA's metatheory: the view from 30,000 feet.

- AURA is defined in a Pure-Type-Systems style.

$$
\begin{array}{rcl}
t & ::= & \textbf{Prop} \mid \textbf{Type}\ldots \\
 & \mid & (\mathrm{x}\colon \mathrm{t}) \rightarrow \mathrm{t} \mid \mathrm{t}\ \textbf{says}\ \mathrm{t}\ldots \\
 & \mid & \lambda \mathrm{x}\colon \mathrm{t}.\ \mathrm{t} \mid \textbf{sign}(\mathrm{t},\ \mathrm{t})\ldots
\end{array}
$$

- Call-by-value reduction ensures $\bot$ isn't confused for a proof.

Theorem (Syntactic Soundness)

Reduction preserves typing; well-typed terms don't get stuck.

Theorem (Decidability of typechecking)

Either $\Sigma; \Gamma \vdash t_1 : t_2$ *or* $\Sigma; \Gamma \nvdash t_1 : t_2$*, constructively.*

Aura's core metatheory formalized in Coq.

- Terms *locally nameless*, with DeBruijn indexed bound variables and named free variables.
- Formalized features: inductive data types, **Prop** and **Type** language fragments, **says** and **pf** modalities. . . .

Development Size (in lines of commented Coq code)	
Definitions	1400
Type Soundness	6000
Decidability of Typechecking	5000

Engineering Formal Metatheory [Aydemir+ 08]

Aura is real.

- Current Features:
  - Interpreter and typechecker for full language
  - Foreign function interface
- Coming Soon:
  - Cryptographic implementation of **sign**
  - Automatic logging
- Future Research:
  - Type inference?
  - Surface syntax?
  - Information flow?
  - Effects tracking?

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Demo

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Interpreter, Coq scripts, and papers available from
`http://www.cis.upenn.edu/~stevez/sol/aura.html`

Bonus Slides

- Access Control Matrices and Capabilities
- Mechanizing AURAwas a positive experience.

Conventional techniques handle the ICFP policy poorly.

Access control matrices

- ICFP server stores the list of owners and delegations.
- Owner must contact ICFP server directly to delegate.
- All participants must trust server's records re: delegation.

Atomic capabilities

- Unforgeable, atomic tokens serve as tickets to play songs.
- Who issues the tokens?

Mechanizing AURA was a positive experience.

- Aura is large.
  - 21 syntactic forms
  - 15 judgments
  - 63 inference rules
- Mechanization helped us manage AURA's complexity. Coq proofs...
  - provided assurance that we hadn't make mistakes.
  - enabled us to experiment without rechecking pages of unaffected proofs.
  - simplified collaboration (source control, etc.).

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