Secrecy by typing in the computational model

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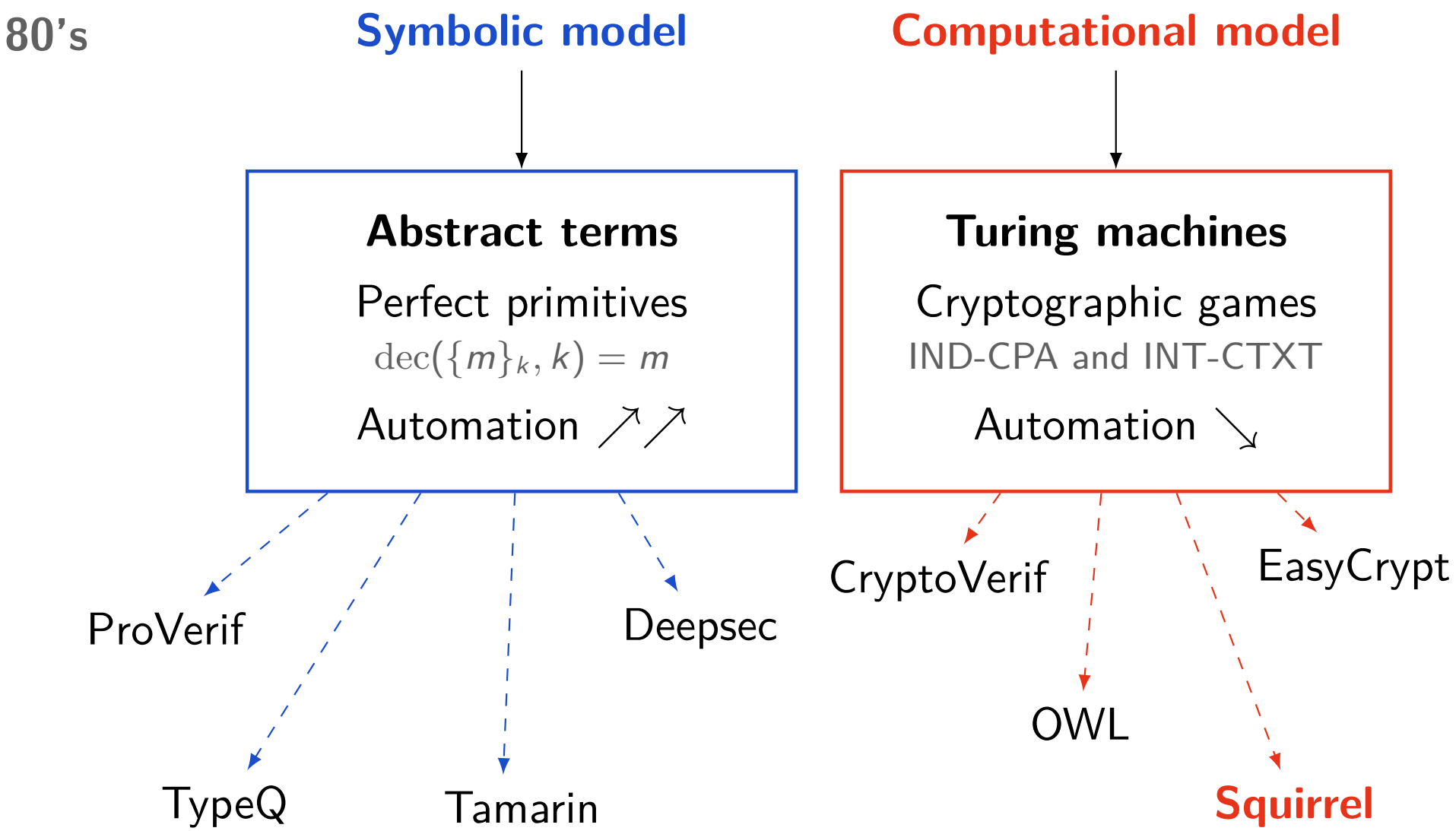
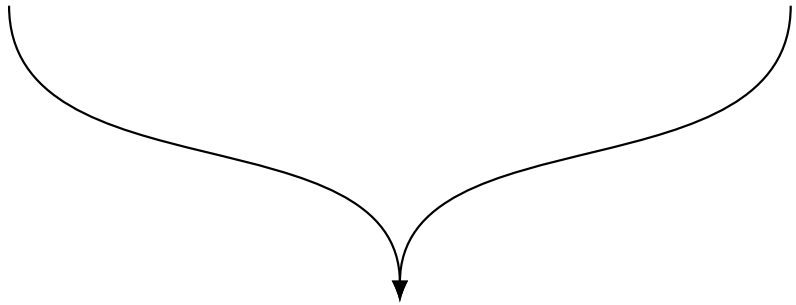
Verification of protocols: two families of models



Verification of protocols: two families of models

80's **Symbolic model** **Computational model**



Computationally Complete Symbolic Attacker

2014 CCSA

Term $t \rightarrow$ Machine $[\![t]\!]$

Squirrel

Squirrel's logic

Wide Mouthed Frog protocol:

$A \to S : a, \{b, k_{ab}\}_{k_a}$

$S \to B : \{a, k_{ab}\}_{k_b}$

3 actions:

Initiator	Server	Responder
$I[i, j, k]$	$S[i, j, k]$	$R[i, j, k]$

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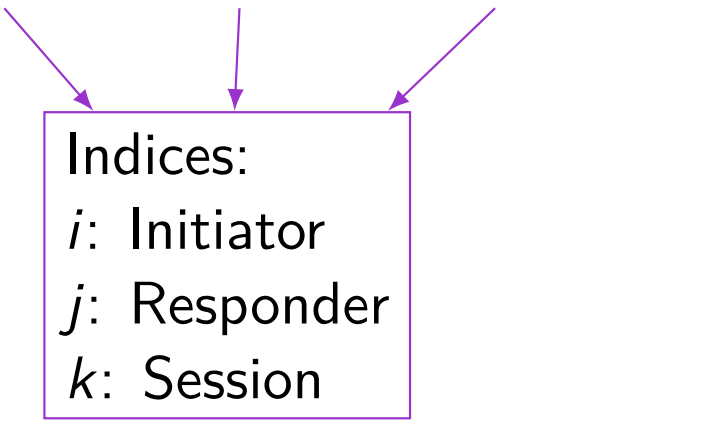

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In each action:
- Output
- Condition
- States' updates

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3 actions:

In each action:
- Output
- Condition
- States' updates

Initiator $I[i, j, k]$ Server $S[i, j, k]$ Responder $R[i, j, k]$

Output:

$\mathsf{senc}(\langle \mathsf{fst}(\mathsf{input@}S[i, j, k]), \mathsf{snd}(\mathsf{sdec}(\mathsf{snd}(\mathsf{input@}S[i, j, k]), k[i]))\rangle, k[j], r[i, j, k])$

Types for security

Principle: Over-approximate a value by a type

$$\frac{x : \mathrm{Msg} \qquad y : \mathrm{Msg}}{\langle x, y \rangle : \mathrm{Msg}}$$

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$$\frac{x : \mathrm{Msg} \qquad y : \mathrm{Msg}}{\langle x, y \rangle : \mathrm{Msg}}$$

Types for secrecy (with symmetric encryption):

- Low: Public
- High: Secret
- SK[T]: Symmetric key for type T
- ...

Types for security

Related Work: Type systems have been used

- In many symbolic models (Focardi & Maffei, 2011)
- In the computational model in OWL (Gancher et al., 2023)

Types for security

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Goal

Design a type system for secrecy for Squirrel's logic (CCSA)

Contributions

1. Design of the type system
2. Soundness result
3. Case studies
4. Asymmetric encryption

Contributions

1. Design of the type system
   $$\Gamma \vdash m : \mathrm{T}$$
2. Soundness result
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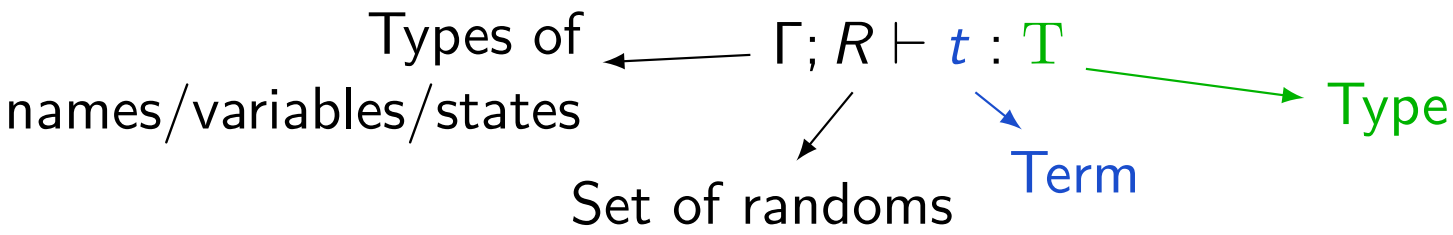
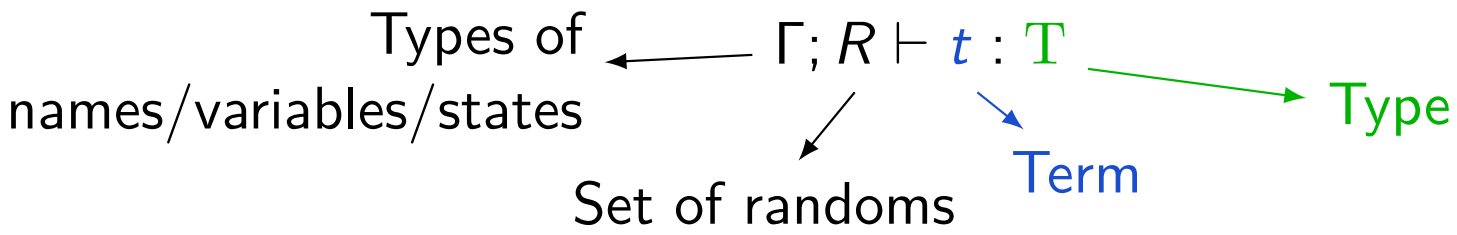
Typing rules



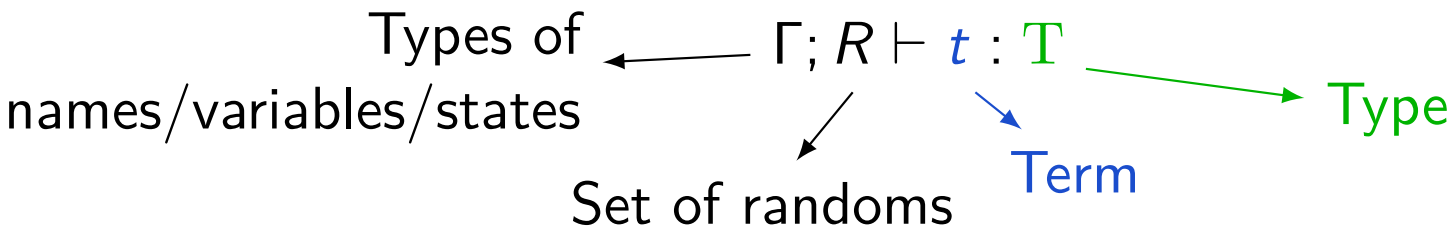
Typing rules



Types:

- Msg
- High; Low
- Bool; Cte(c)
- T + T
- T × T

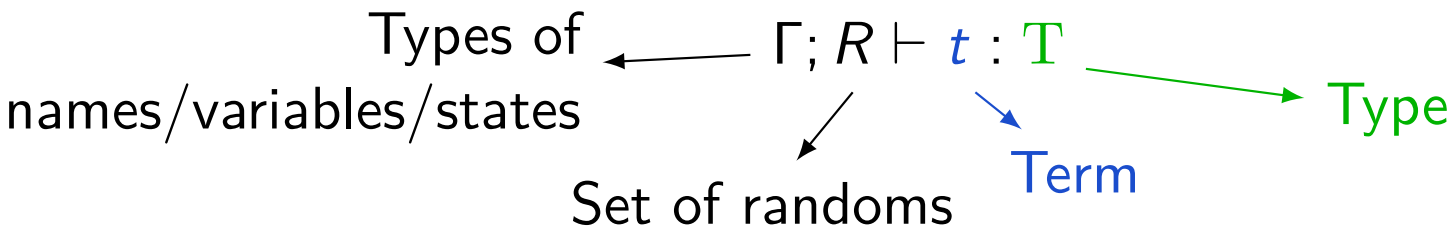
Typing rules



Zeros: $$\frac{\Gamma; R \vdash t : \mathrm{Msg}}{\Gamma; R \vdash \mathsf{zeros}(t) : \mathrm{Low}}$$

Pair: $$\frac{\Gamma; R_1 \vdash t_1 : \mathrm{T}_1 \qquad \Gamma; R_2 \vdash t_2 : \mathrm{T}_2}{\Gamma; R_1 \sqcup R_2 \vdash \langle t_1, t_2 \rangle : \mathrm{T}_1 \times \mathrm{T}_2}$$

Typing rules



Encryption:
$$\frac{\Gamma; R \vdash t : \mathrm{T} \qquad \Gamma(k) = \mathrm{SK[T]}}{\Gamma; R \sqcup \{r\} \vdash \mathsf{senc}(t, k[\vec{j}], r[\vec{i}]) : \mathrm{Low}}$$

Decryption:
$$\frac{\Gamma; R \vdash t : \mathrm{Low} \qquad \Gamma(k) = \mathrm{SK[T]}}{\Gamma; R \vdash \mathsf{sdec}(t, k[\vec{j}]) : \mathrm{T} + \mathrm{Cte(fail)}}$$

Contributions

1 Design of the type system

2 Soundness result

Soundness

If $\Gamma \vdash t : \mathrm{Low}$ and $\Gamma \vdash s : \mathrm{High}$
Then a computational attacker cannot deduce $[\![s]\!]$ from $[\![t]\!]$

3 Case studies

4 Asymmetric encryption

Proof sketch

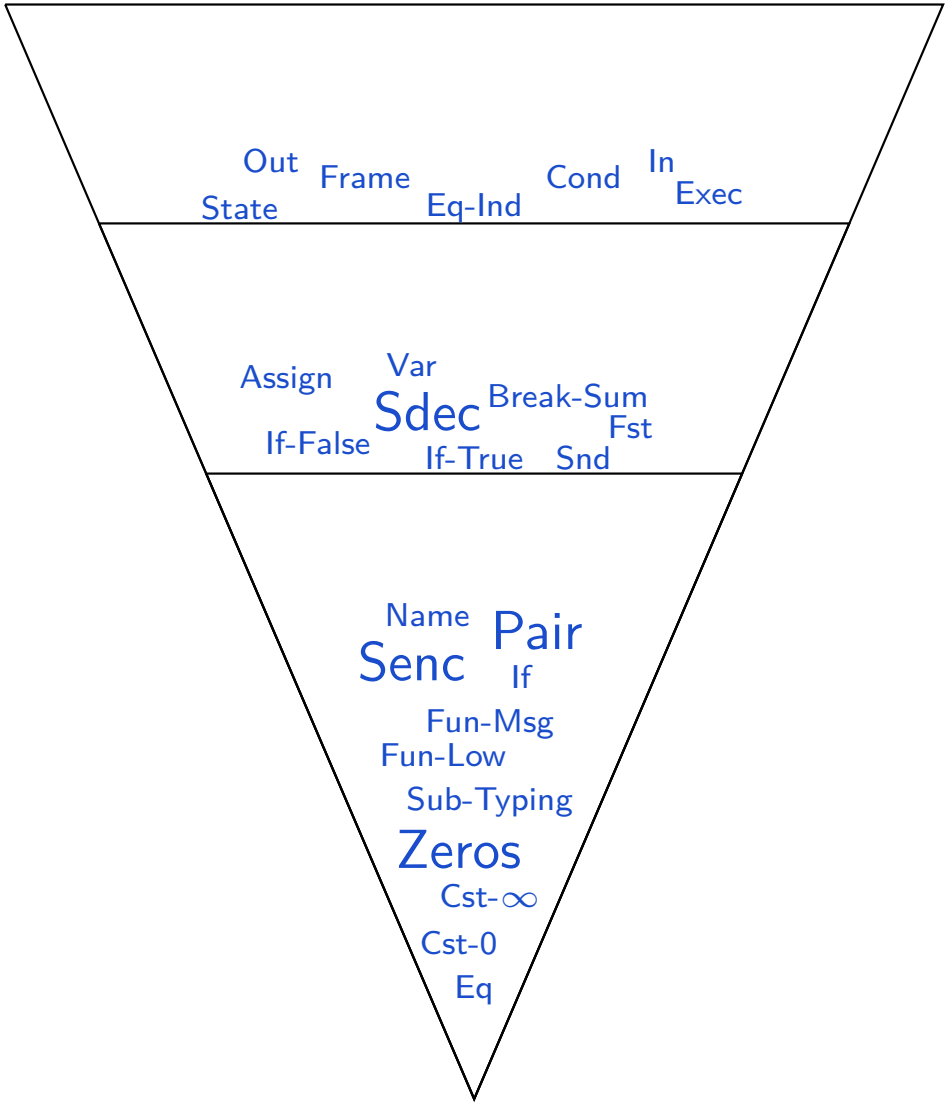
Sdec

Senc Pair

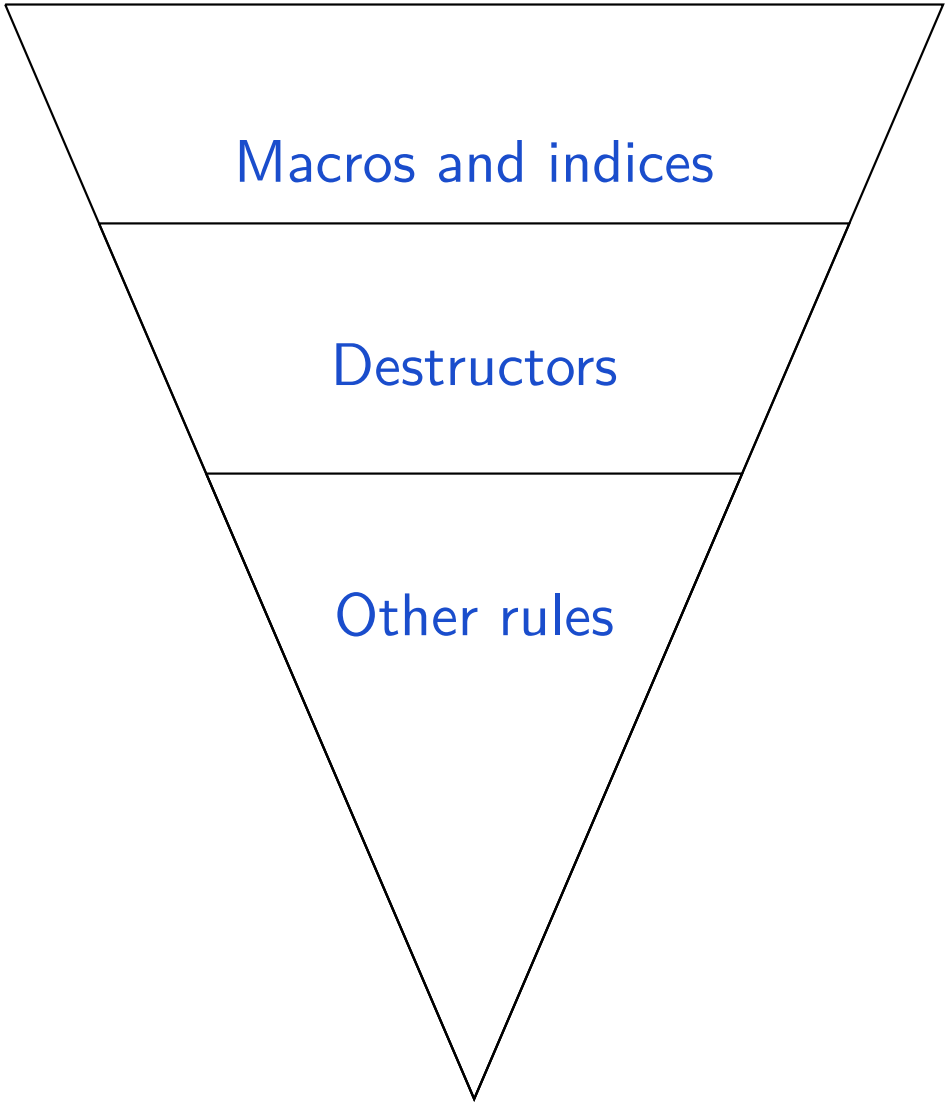
Zeros

Proof sketch

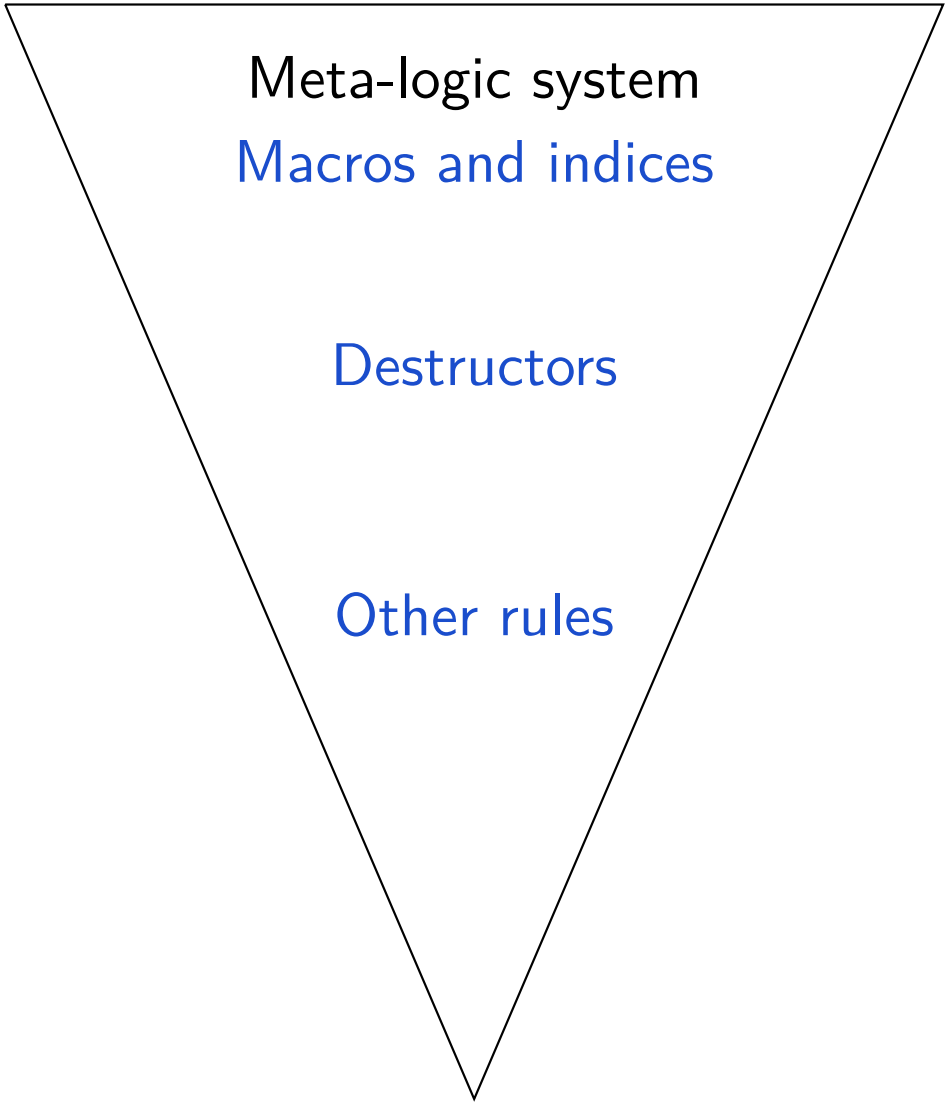
Proof sketch



Proof sketch



Proof sketch



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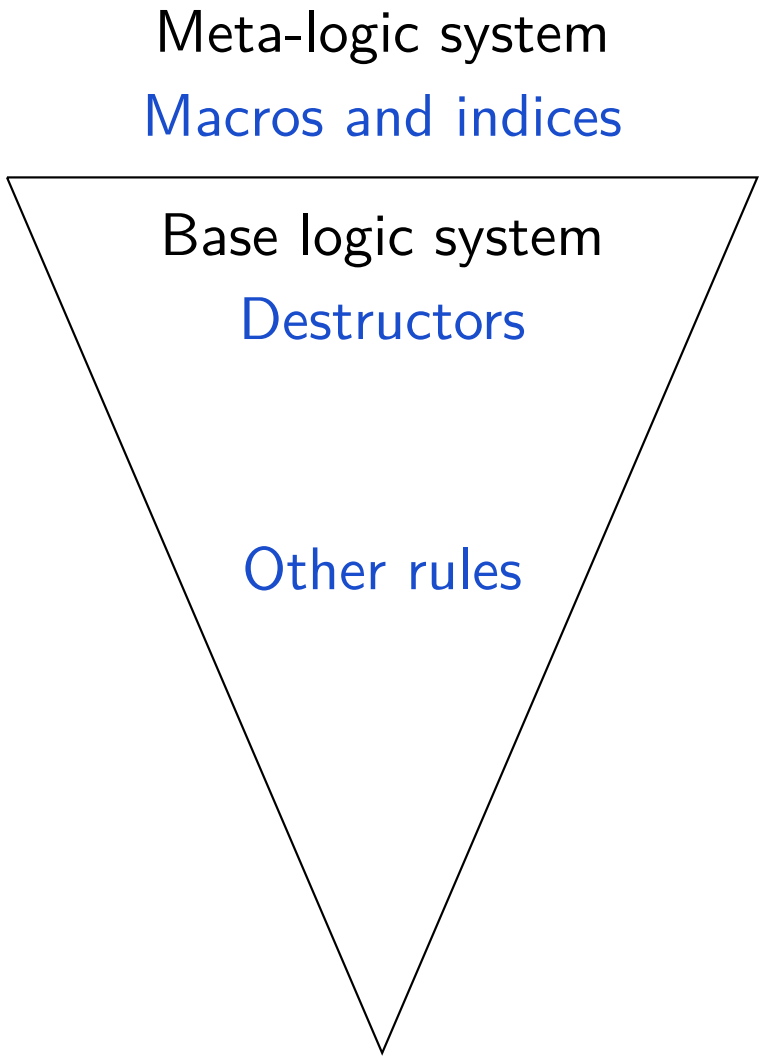

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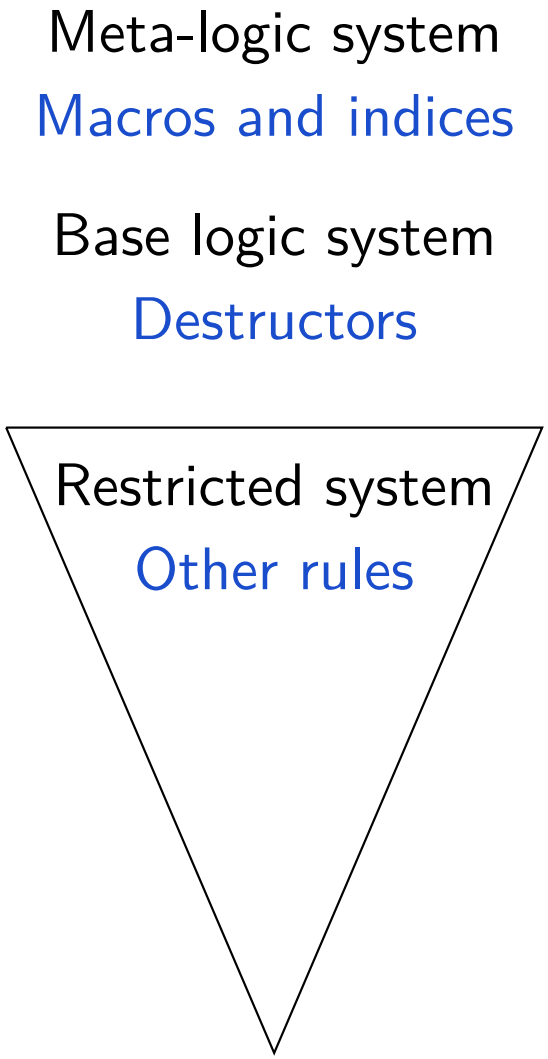

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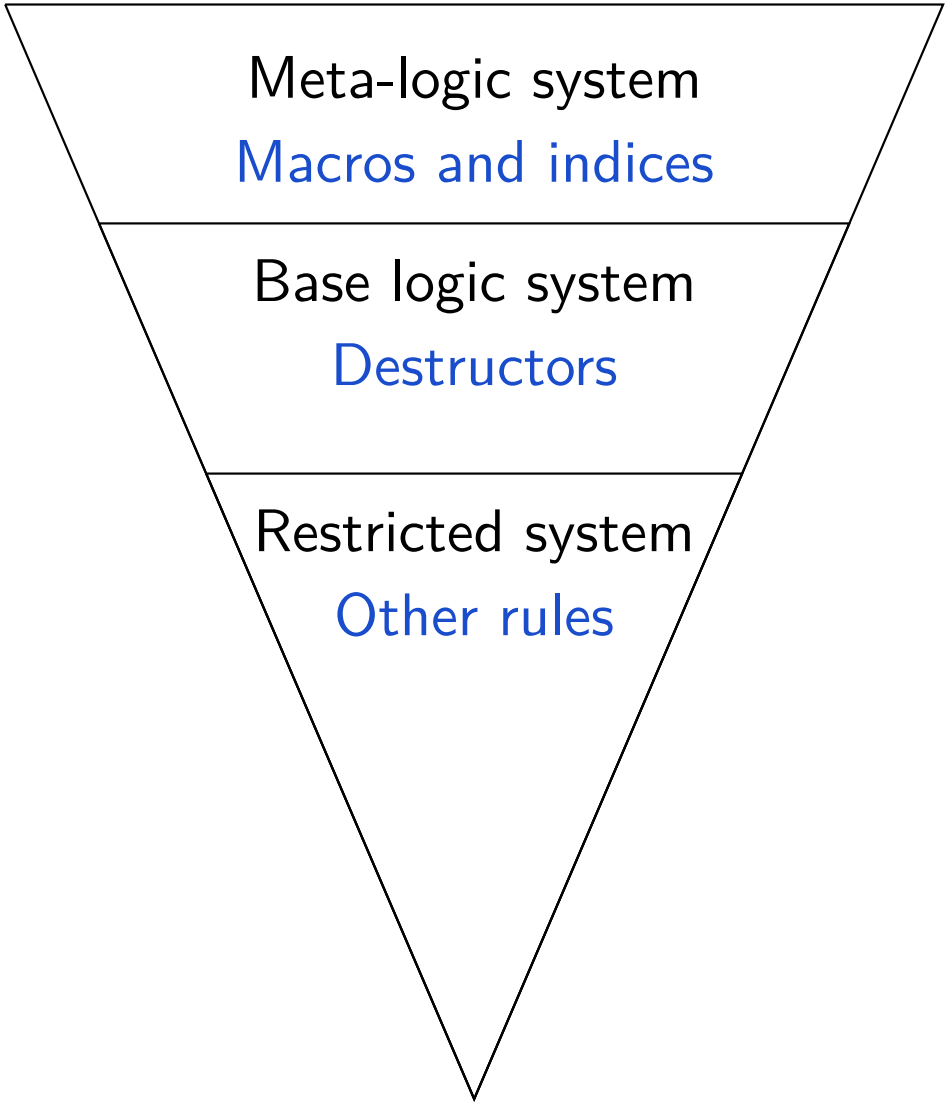
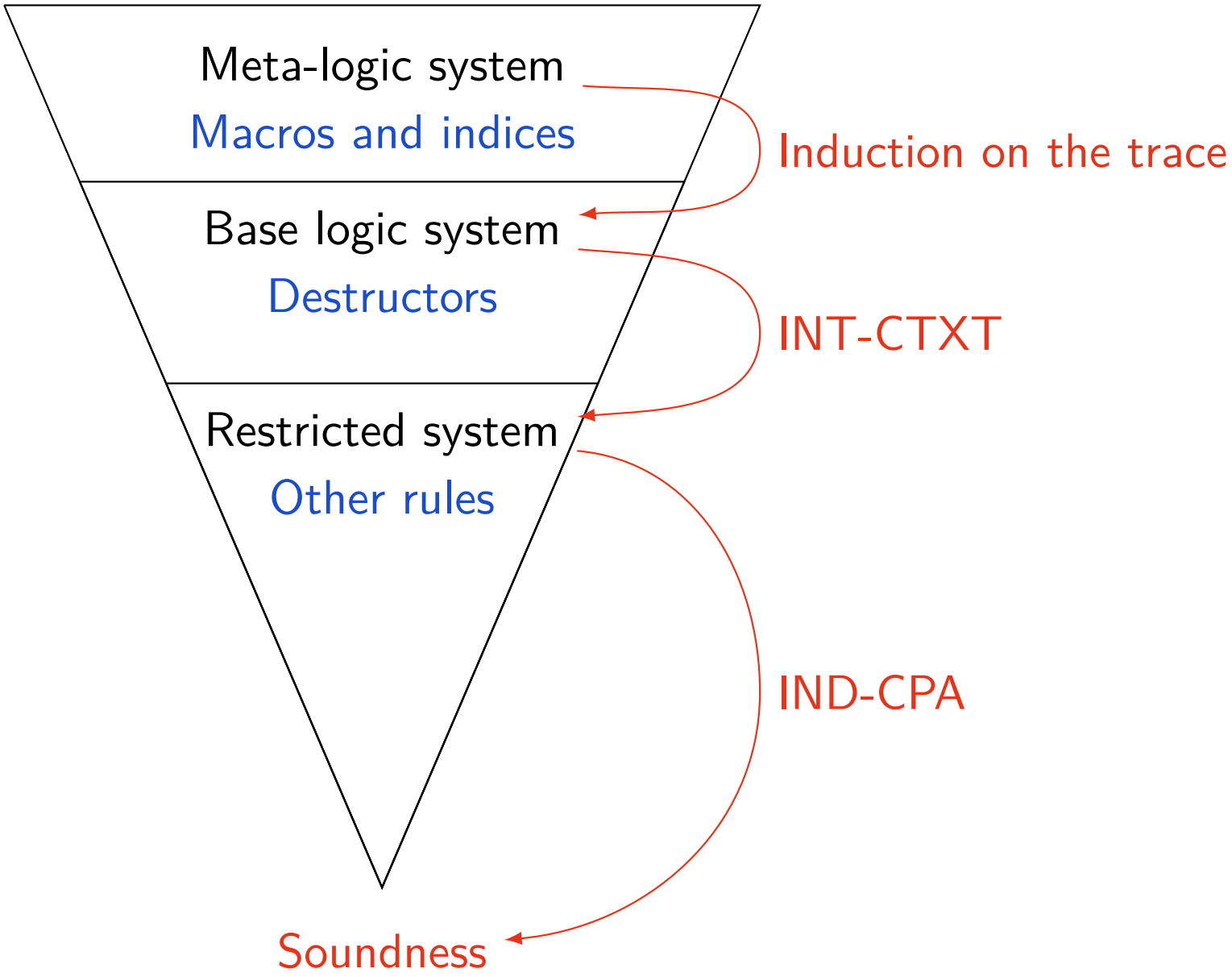


Soundness

Proof sketch



Use of the theorem

Soundness

If $\Gamma \vdash t : \mathrm{Low}$ and $\Gamma \vdash s : \mathrm{High}$
Then a computational attacker cannot deduce $[\![s]\!]$ from $[\![t]\!]$

If a protocol is well typed in $\Gamma; R$

If a term t type High

The attacker cannot find $[\![t]\!]$ with the frame of the protocol

Use of the theorem

Soundness

If $\Gamma \vdash t : \mathrm{Low}$ and $\Gamma \vdash s : \mathrm{High}$
Then a computational attacker cannot deduce $[\![s]\!]$ from $[\![t]\!]$

If a protocol is well typed in $\Gamma; R$ →

In each action:
- Output types Low
- Condition types Bool
- States types as indicated in Γ

If a term t type High

The attacker cannot find $[\![t]\!]$ with the frame of the protocol

Contributions

1. Design of the type system
2. Soundness result
3. Case studies
4. Asymmetric encryption

Case studies

	no tag	tags
Wide Mouth Frog	✓	✓
Denning Sacco	✗	✓
Otways-Rees	✗	✓
Needham-Schroeder*	✗	✓
Yahalom*	✗	✓
Yahalom-Paulson*	✗	✓
Mechanism 6$^\diamond$	-	✓
Mechanism 9$^\diamond$	-	✓
Mechanism 13$^\diamond$	-	✓

$^\diamond$: ISO/IEC 11770 standard part II

* : Without last message

Focus on Wide Mouth Frog

Protocol:

$A \to S : a, \{b, k_{ab}\}_{k_a}$

$S \to B : \{a, k_{ab}\}_{k_b}$

Scenario with **dishonest agents**:

7 actions $\to$ 7 outputs and conditions to type.

Focus on Wide Mouth Frog

Protocol:

$A \to S : a, \{b, k_{ab}\}_{k_a}$
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Scenario with **dishonest agents**:

7 actions $\to$ 7 outputs and conditions to type.

Result:

If A send k_{ab} to an honest agent k_{ab} is secret.
If B receive k_{ab} from an honest agent k_{ab} is secret.

Contributions

1. Design of the type system
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New rules for IND-CCA2 asymmetric encryption

Public key: PK

$$\frac{\Gamma(k) = \mathrm{AK}[\mathrm{T}]}{\Gamma; R \vdash \mathsf{pk}(k[\vec{j}]) : \mathrm{Low}}$$

Encryption: Aenc

$$\frac{\Gamma; R \vdash t : \mathrm{T} \qquad \Gamma(k) = \mathrm{AK}[\mathrm{T}]}{\Gamma; R \sqcup \{r\} \vdash \mathsf{aenc}(t, \mathsf{pk}(k[\vec{j}]), r[\vec{i}]) : \mathrm{Low}}$$

Decryption: Adec

$$\frac{\Gamma; R \vdash t : \mathrm{Low} \qquad \Gamma(k) = \mathrm{AK}[\mathrm{T}]}{\Gamma; R \vdash \mathsf{adec}(t, k[\vec{j}]) : \mathrm{T} + \mathrm{Low}}$$

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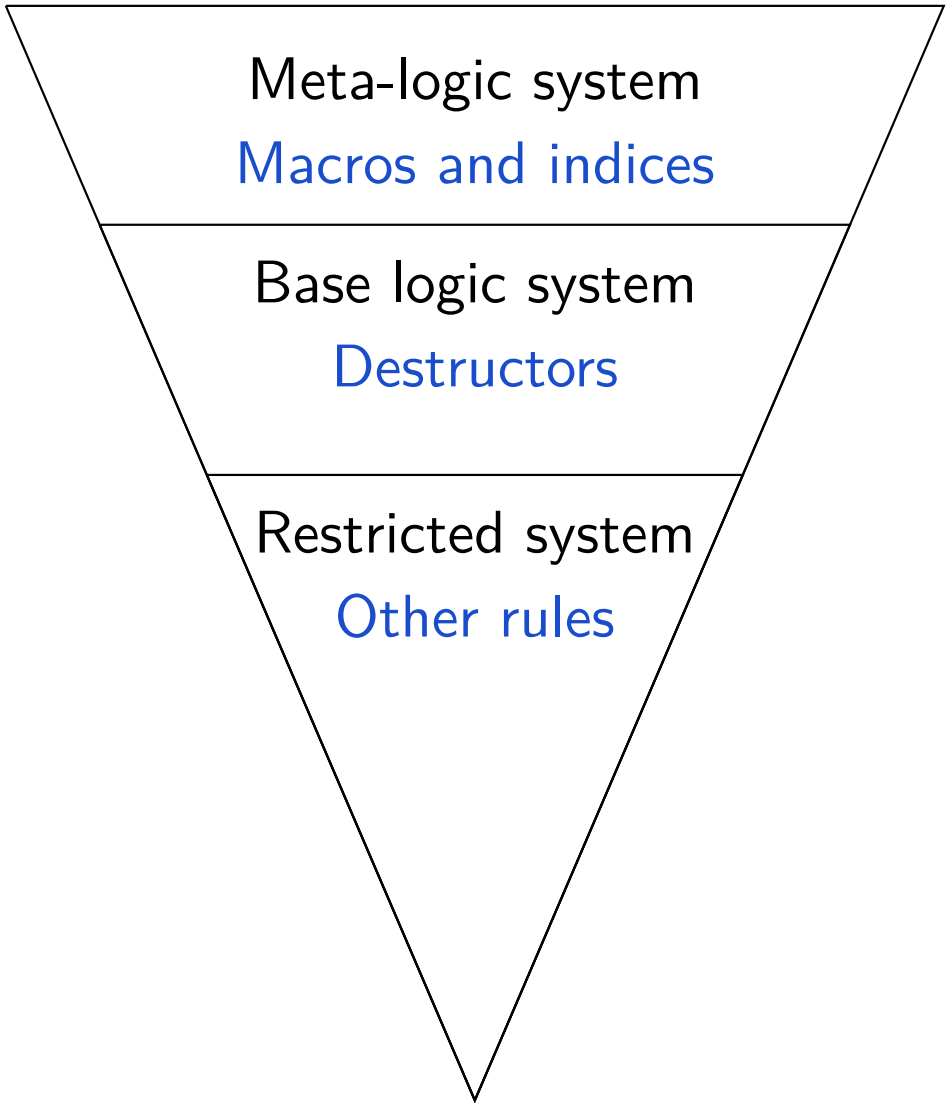

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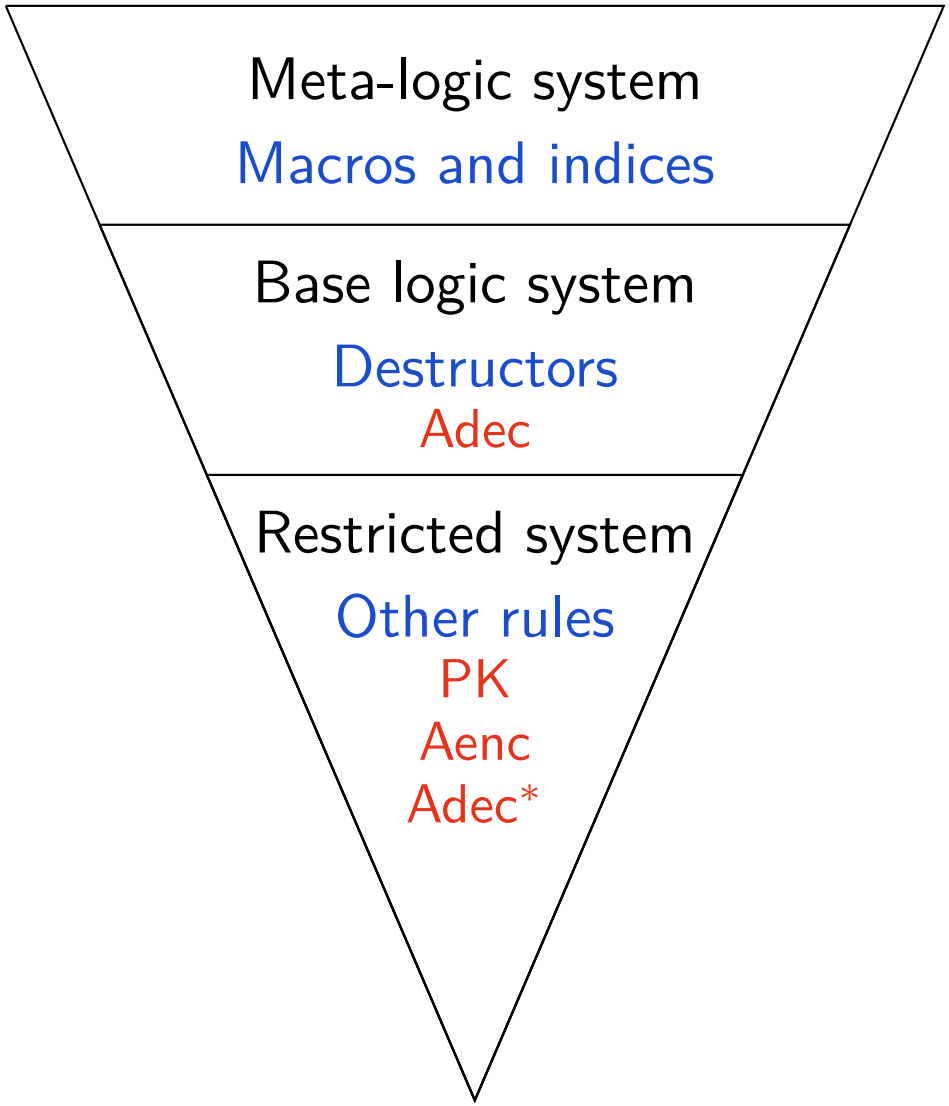

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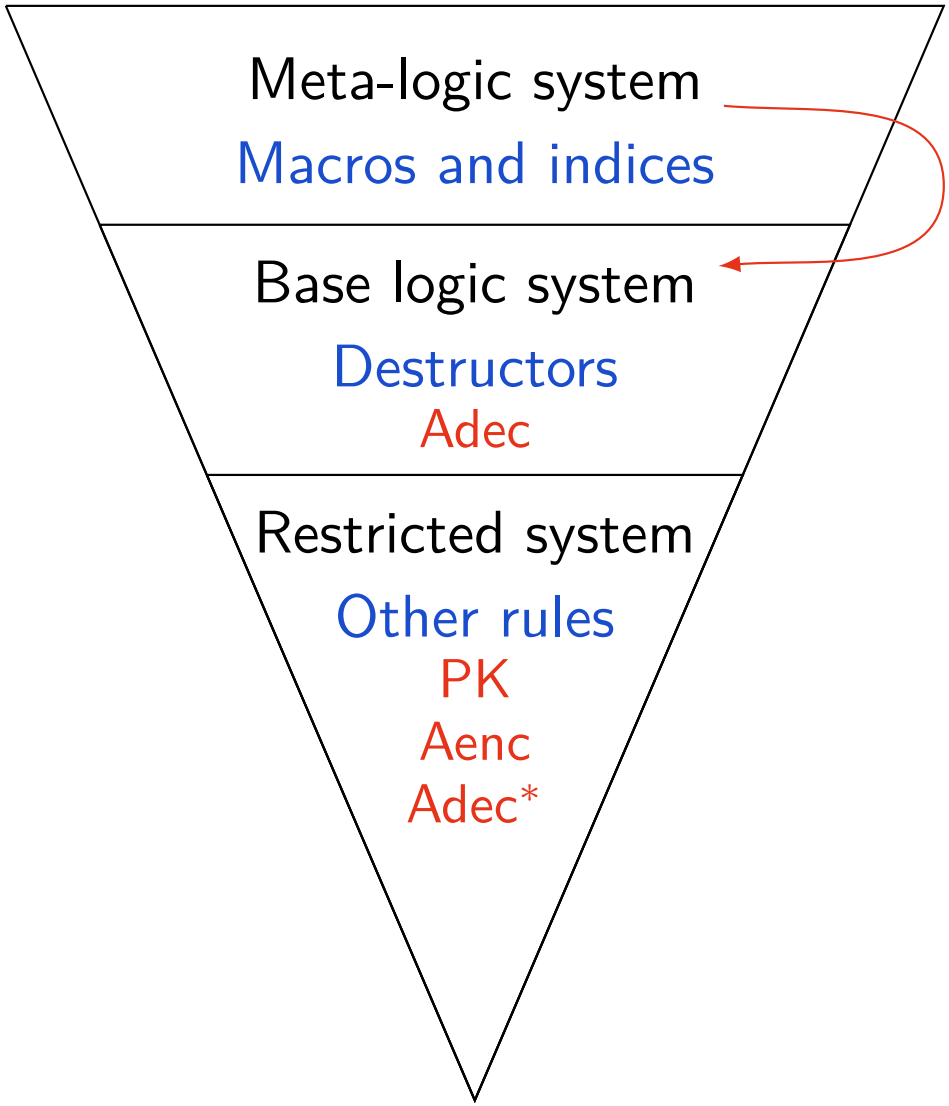

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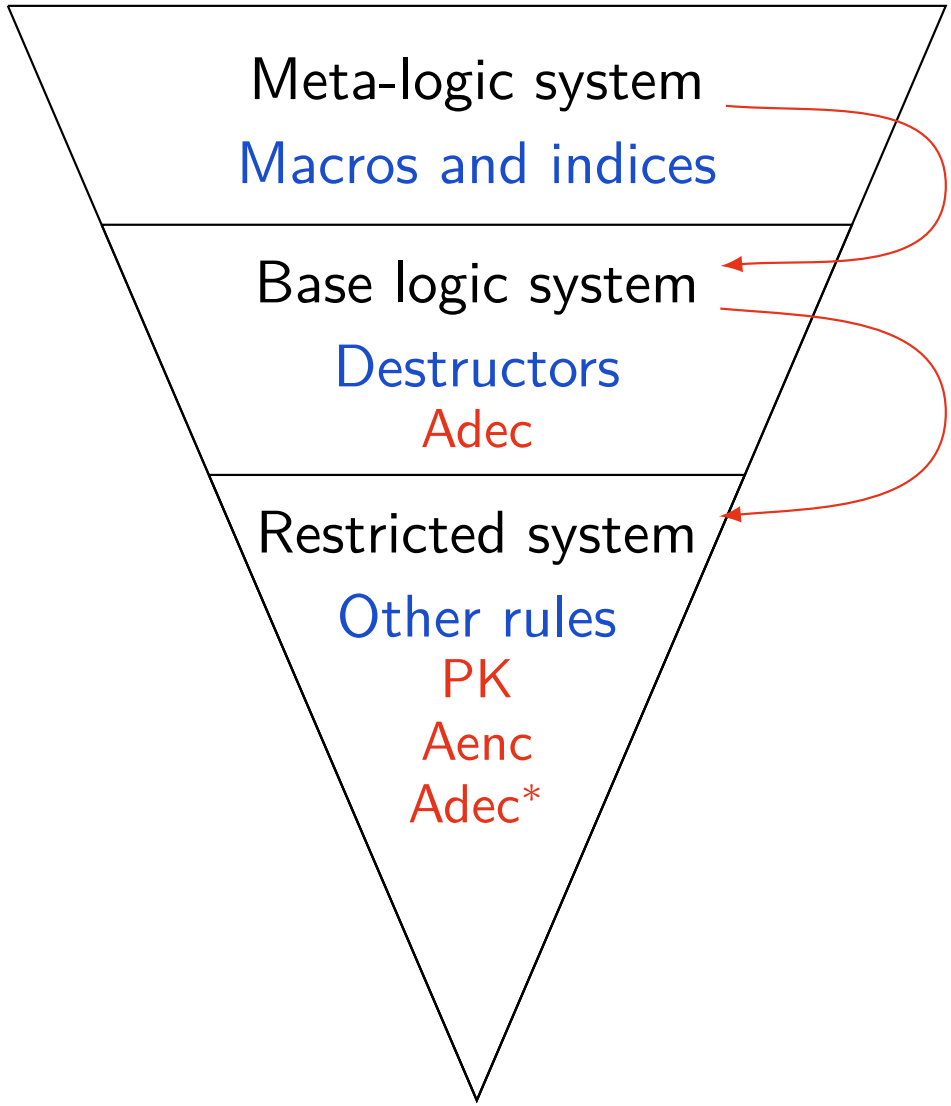

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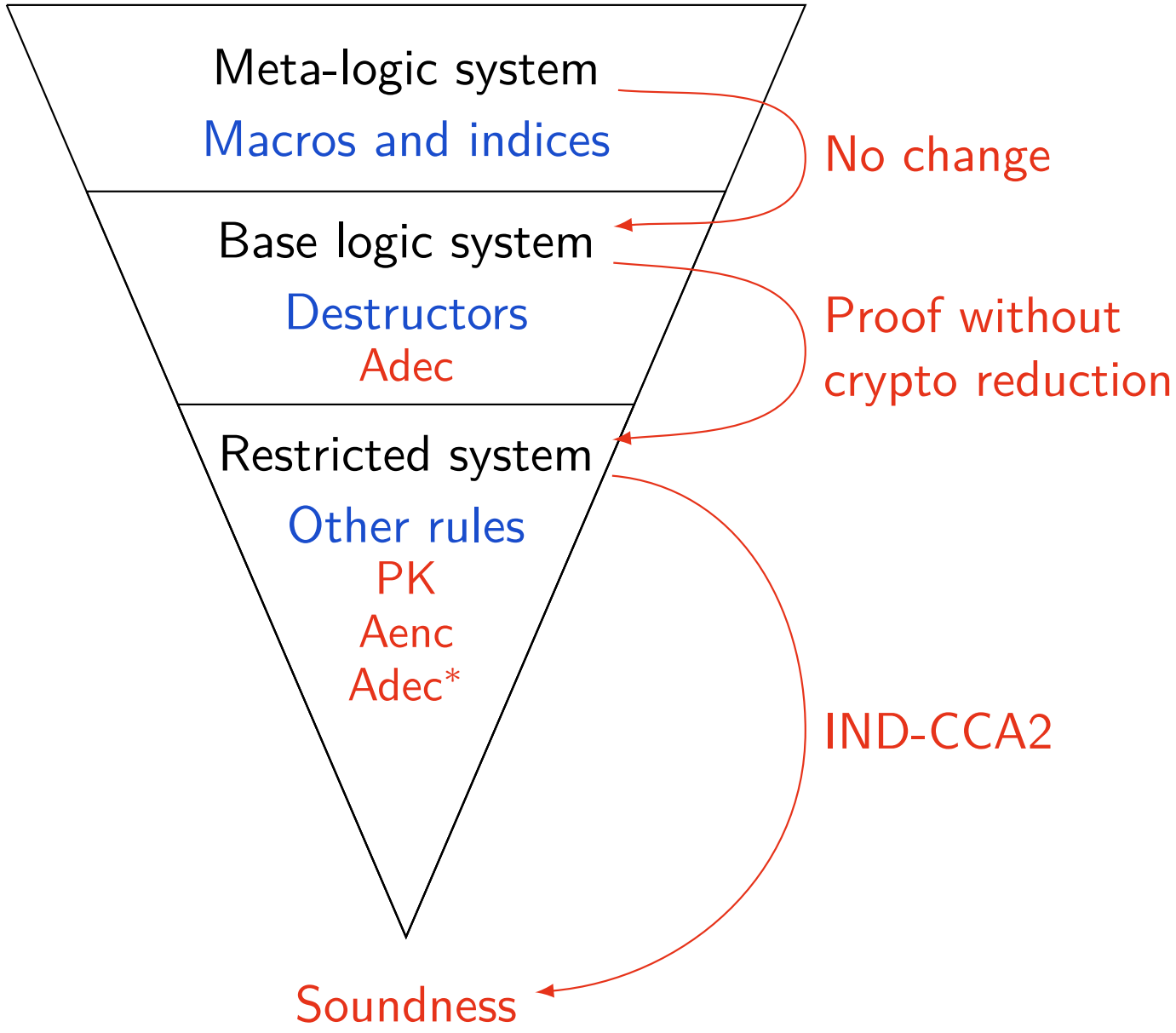

Case studies for asymmetric encryption

Needham-Schroeder-Lowe:

✓ (partial)

ISO/IEC 11770 standard part II - Mechanism 6:

✓ (partial)

Conclusion and ongoing work

Conclusion:

- A type system for secrecy in a computational model
  Symmetric/asymmetric encryption
- Soundness proof

Ongoing work:

- Add primitives
  hash function, signature...
- Key establishment protocol
  Key usability
- Integration in **Squirrel**