Deciding equivalence properties in security protocols

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Security protocols

Google SSO

BAC (e-passport)

Helios (e-voting)

TLS 1.3 (prior ver.)

WPA2 (wifi)

Security protocols

Google SSO

☠ Armando *et al.* (2008)

BAC (e-passport)

☠ Chothia and Smirnov (2010)

Helios (e-voting)

☠ Cortier and Smyth (2011)

TLS 1.3 (prior ver.)

☠ Cremers *et al.* (2016)

WPA2 (wifi)

☠ Vanhoef and Piessens (2017)

Security protocols

The attacker can...

- Read / Write
- Intercept

But they do not...

- Break cryptograhy
- Use side channels

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Dolev-Yao models

Concurrent systems where dishonest parties have complete control over inter-process communication

but cryptography is idealised

Security properties

Reachability

Bad event in one system

- Authentication
- (weak) secrecy

Equivalence

Privacy as indistinguishability

- Anonymity
- Vote privacy
- Unlinkability

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Reachability ✓

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Equivalence ?

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Tool support

Equivalence

Privacy as indistinguishability

Tamarin	Maude-NPA	ProVerif	Akiss	SAT-equiv	SPEC

Tool support

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may not terminate

bounded number of protocol sessions

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Privacy as indistinguishability

may not terminate: Tamarin, Maude-NPA, ProVerif

bounded number of protocol sessions: Akiss, SAT-equiv, SPEC

Tamarin | Maude-NPA | ProVerif | Akiss | SAT-equiv | SPEC

approximation of equivalence (false attacks): Tamarin, Maude-NPA, ProVerif, Akiss

Tool support

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Privacy as indistinguishability

may not terminate

bounded number of protocol sessions

Tamarin | Maude-NPA | ProVerif | Akiss | SAT-equiv | SPEC

approximation of equivalence (false attacks)

crypto limited to a few (common) primitives

Contributions

DEEPSEC prover

may not terminate

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bounded number of protocol sessions

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DEEPSEC prover

~~may not terminate~~

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bounded number of protocol sessions

exact procedure for trace equivalence

any subterm convergent constructors/destructors

Contributions

DEEPSEC prover

~~may not terminate~~

~~approximation of equivalence (false attacks)~~

exact procedure for trace equivalence

~~crypto limited to a few (common) primitives~~

any subterm convergent constructors/destructors

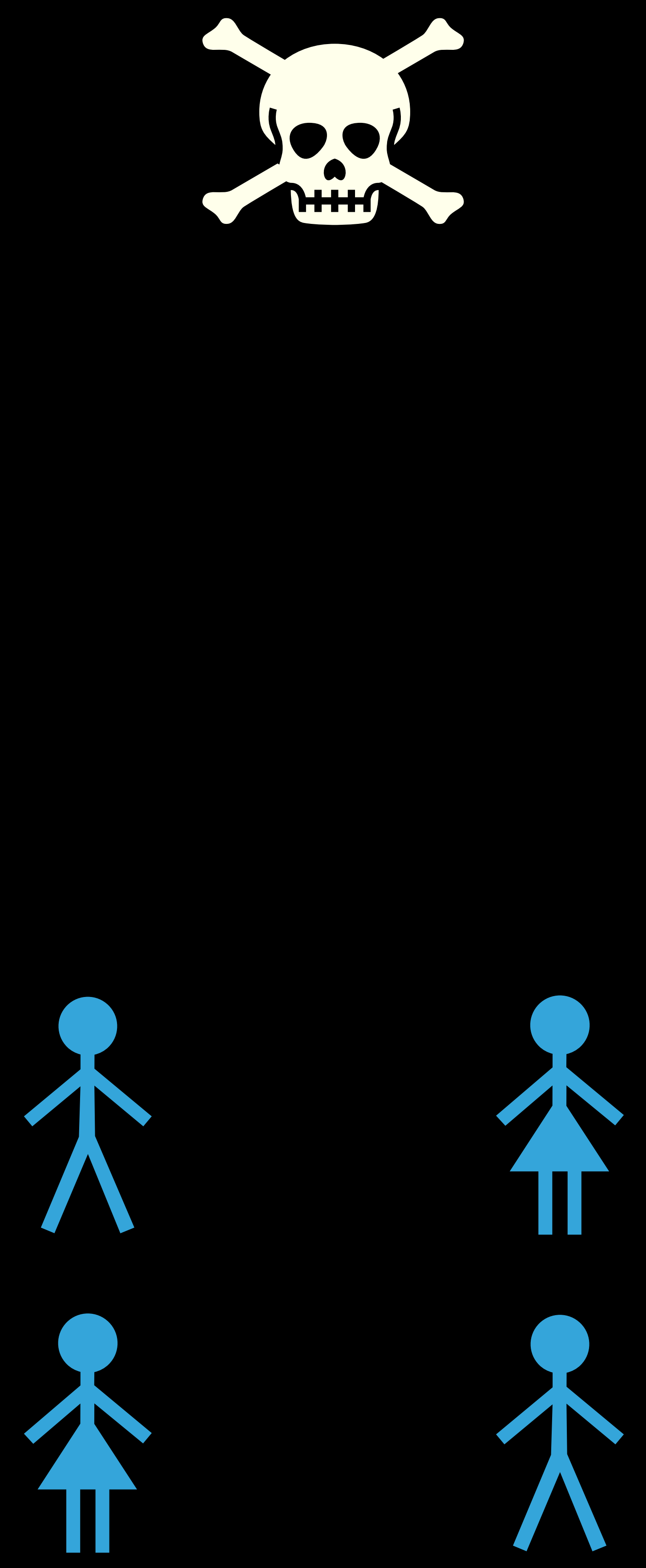
bounded number of protocol sessions

+ running implementation

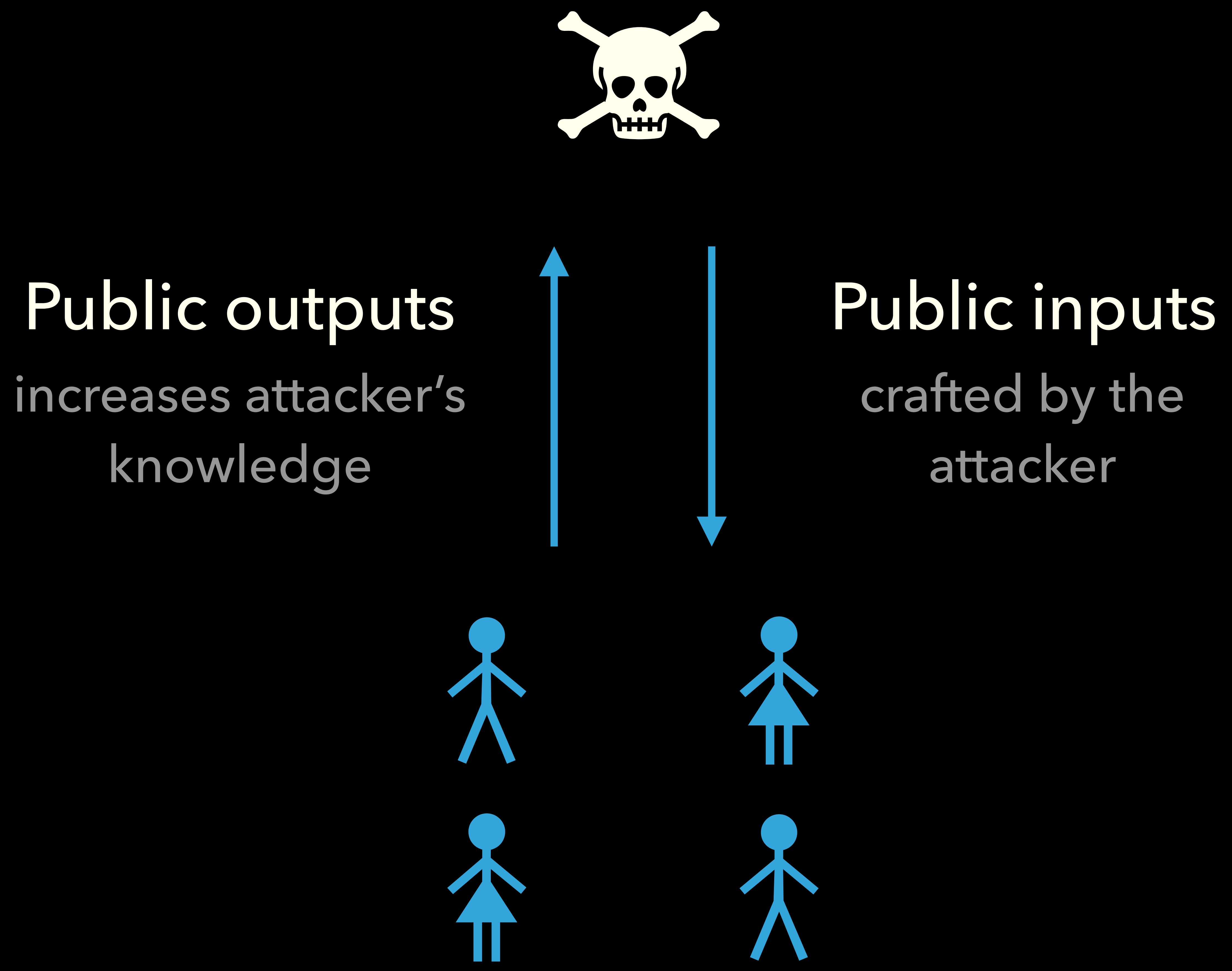
+ tight complexity analysis of the problem

ANALYSING FINITE PROCESSES

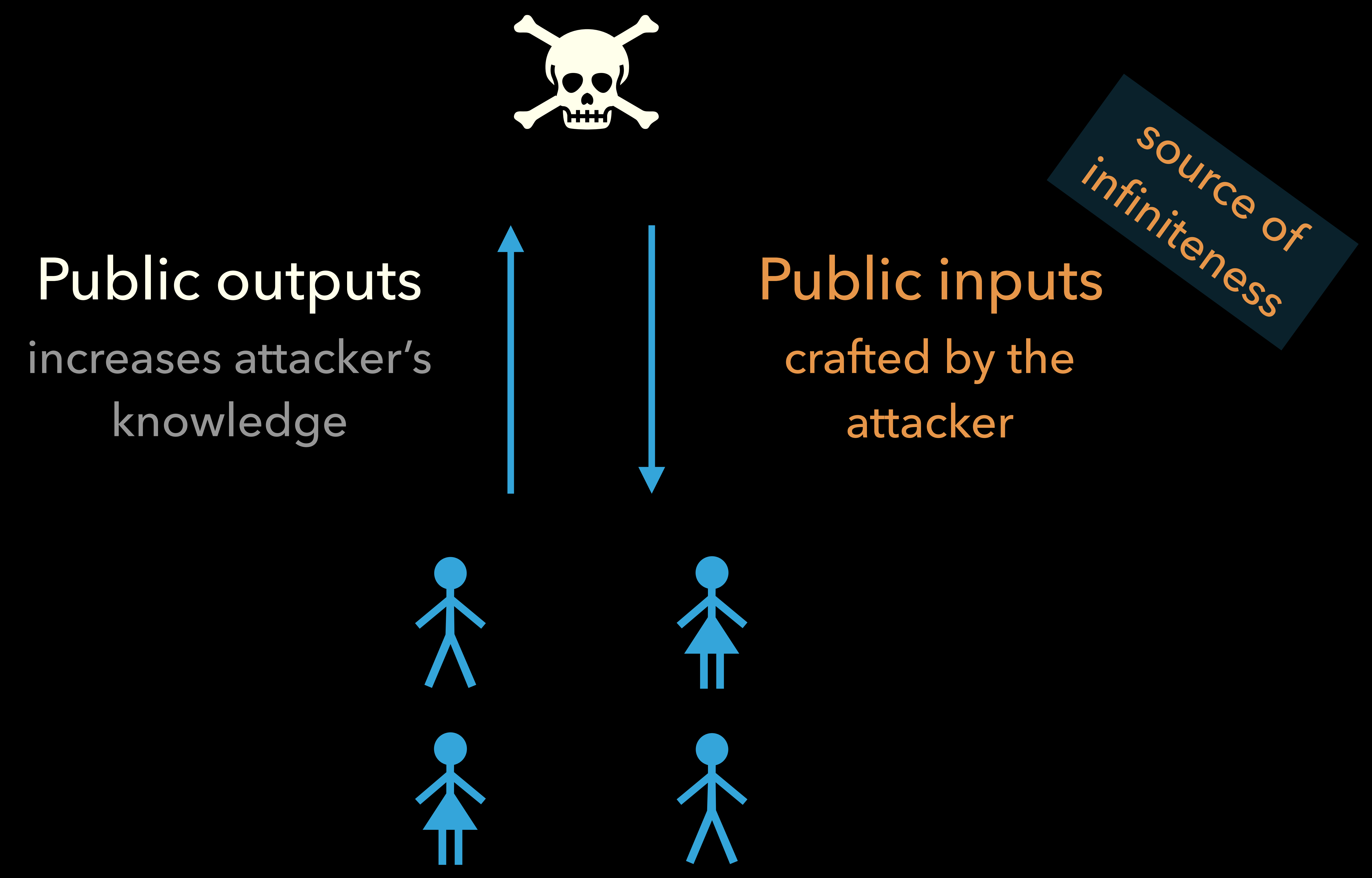
The problem



The problem


Public outputs
increases attacker's knowledge
Public inputs
crafted by the attacker

The problem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The problem

source of infiniteness

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The problem

source of infiniteness

Public outputs

increases attacker's knowledge

↓

Symbolic knowledge base

Public inputs

crafted by the attacker

↓

Symbolic inputs

finite

Handling the symbolic setting

Symbolic knowledge base + Symbolic inputs

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Symbolic knowledge base + Symbolic inputs

Symbolic constraints

to characterize symbolic traces

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Symbolic knowledge base + Symbolic inputs

Symbolic constraints

to characterize symbolic traces

$$X \vdash^? x$$

Deducibility constraints

ability for the attacker to craft *x* (modulo crypto primitives)

$$x \stackrel{?}{=} y$$

Equations

equality of two terms

Decidability

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Ingredients

Most general solutions

of a symbolic trace

+

Tree of sets of symbolic traces

built by constraint solving
equivalence = reachability of a **BAD** node

Comparison to other tools

	#Agents	AKISS	SATEQUIV	DEEPSEC
Wide-Mouth Frog (strong secrecy)	6 ✓	<1s	<1s	<1s
	12 ✓	22min	<1s	<1s
	23 ✓	OOM	<1s	3s
Helios Vanilla (vote privacy)	6 ⚡	47s	–	<1s
Helios Weeding	6 ✓	OOM	–	1s
Helios Zero-KP	6 ✓	OOM	–	2s
Helios W revote	11 ⚡	OOM	–	2s
Helios ZKP revote	11 ✓	OOM	–	2h 42min

✓ security proof ⚡ security violation – cannot be specified OOM out of memory

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COULDN'T IT BE MORE EFFICIENT?

For subterm convergent crypto

☠ Passive attacker

PTIME

with fixed cryptographic primitives

☠ Active attacker

coNP-complete

if no **else** branches +
each honest agent uses a different channel

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☠ Passive attacker

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with fixed cryptographic primitives

coNP-complete *new !*

in general

☠ Active attacker

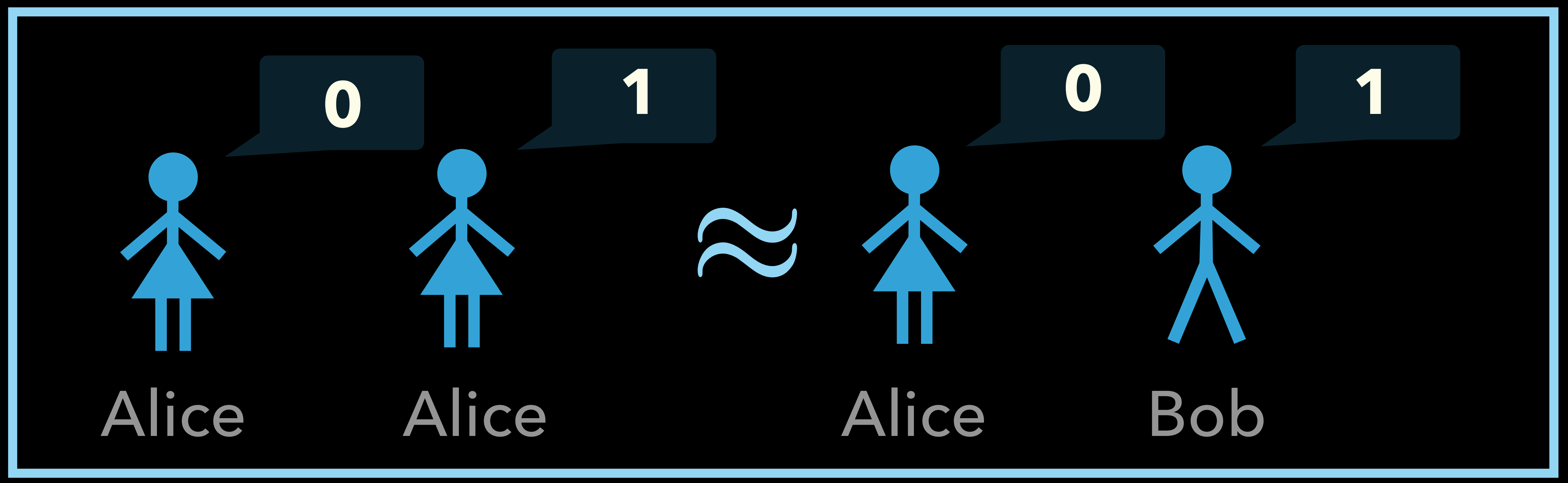
coNP-complete

if no **else** branches + each honest agent uses a different channel

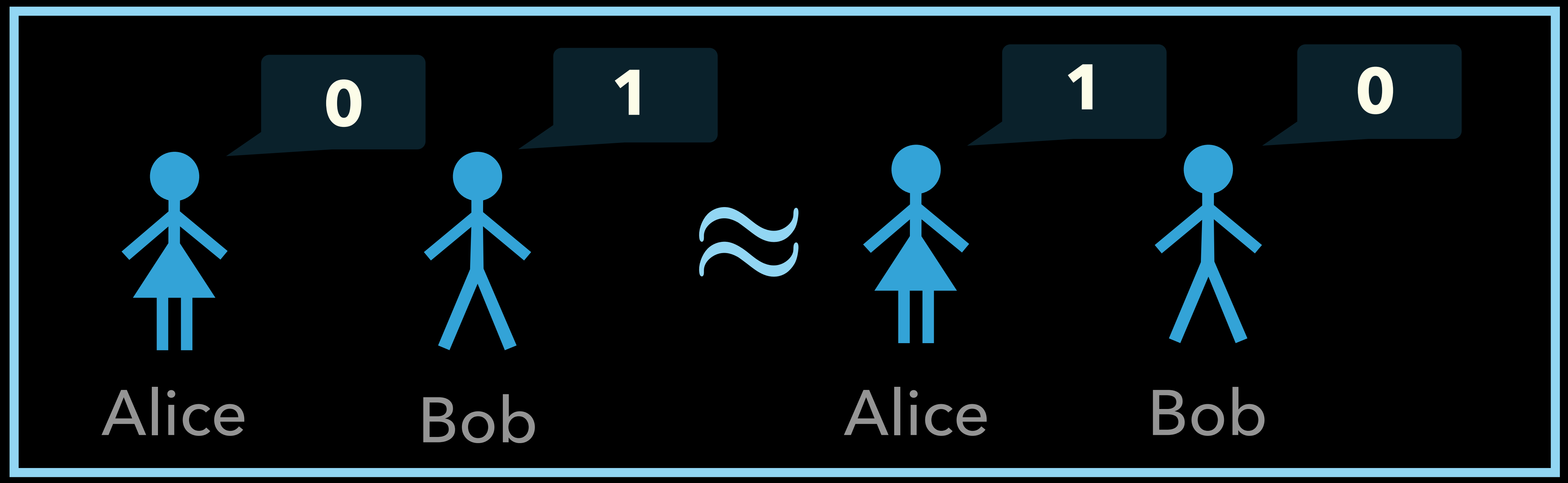
coNEXP-complete *new !*

in general

But in practice?

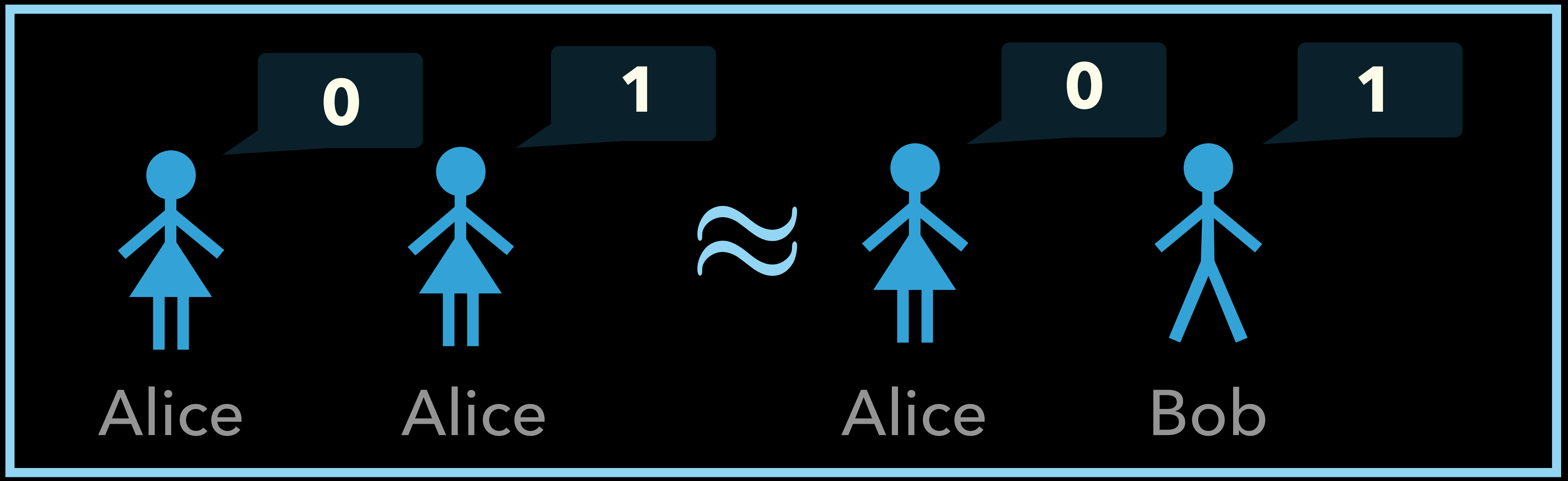


Unlinkability



Vote privacy

But in practice?



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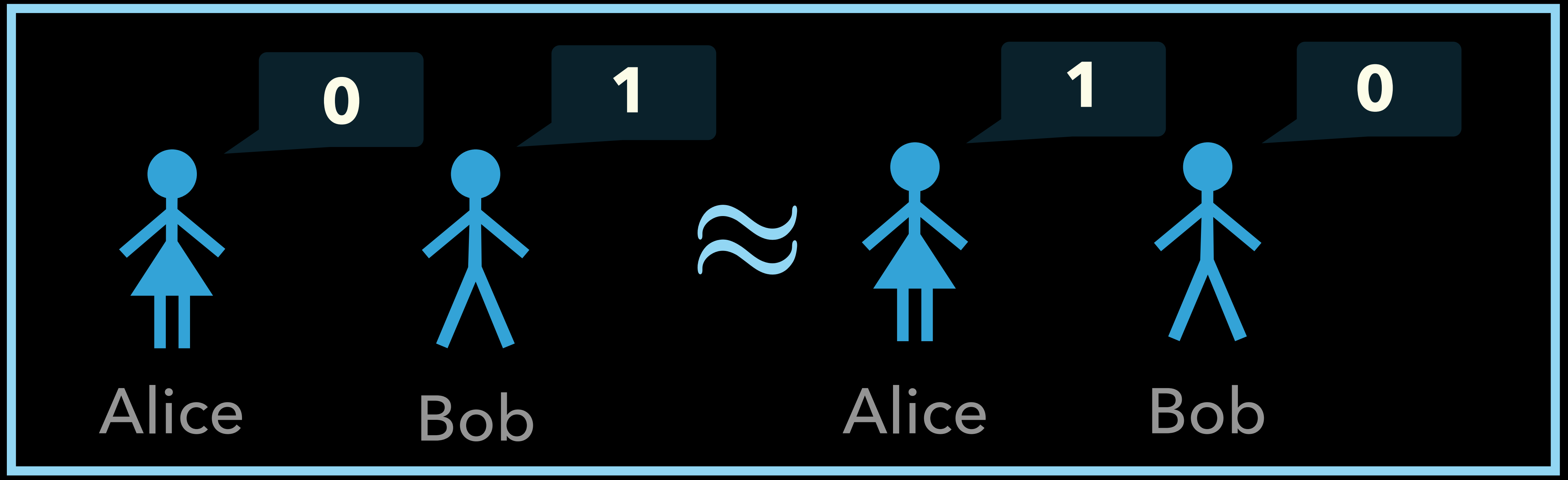
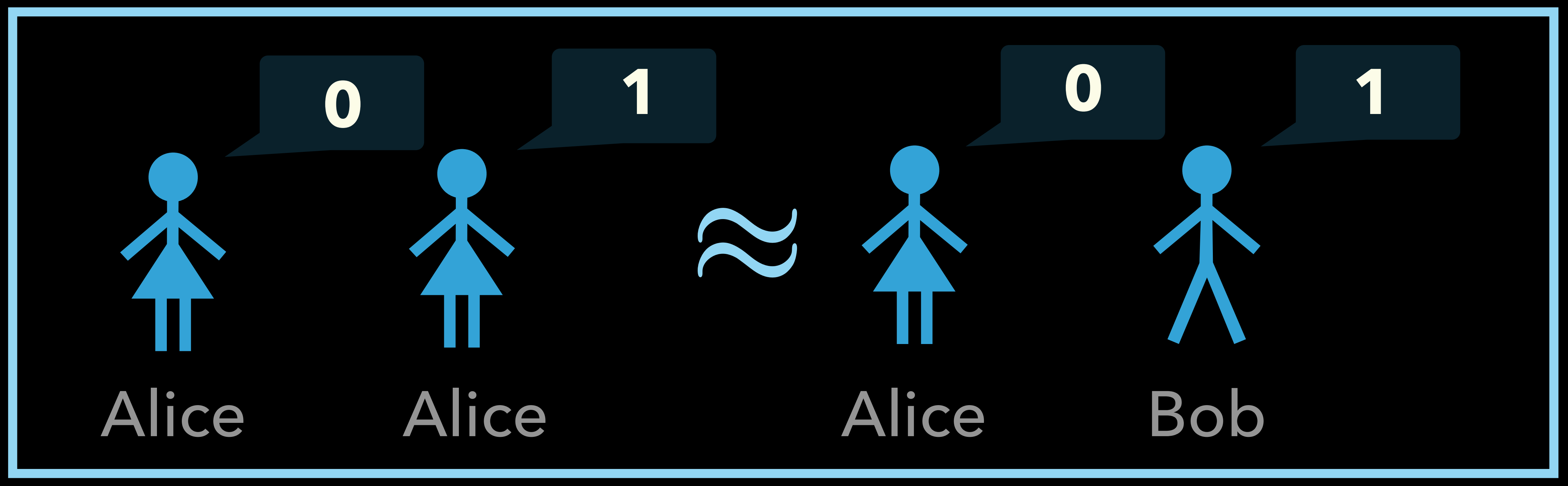


Vote privacy

Observation

In practice, we check equivalence
of processes with similar structure

But in practice?



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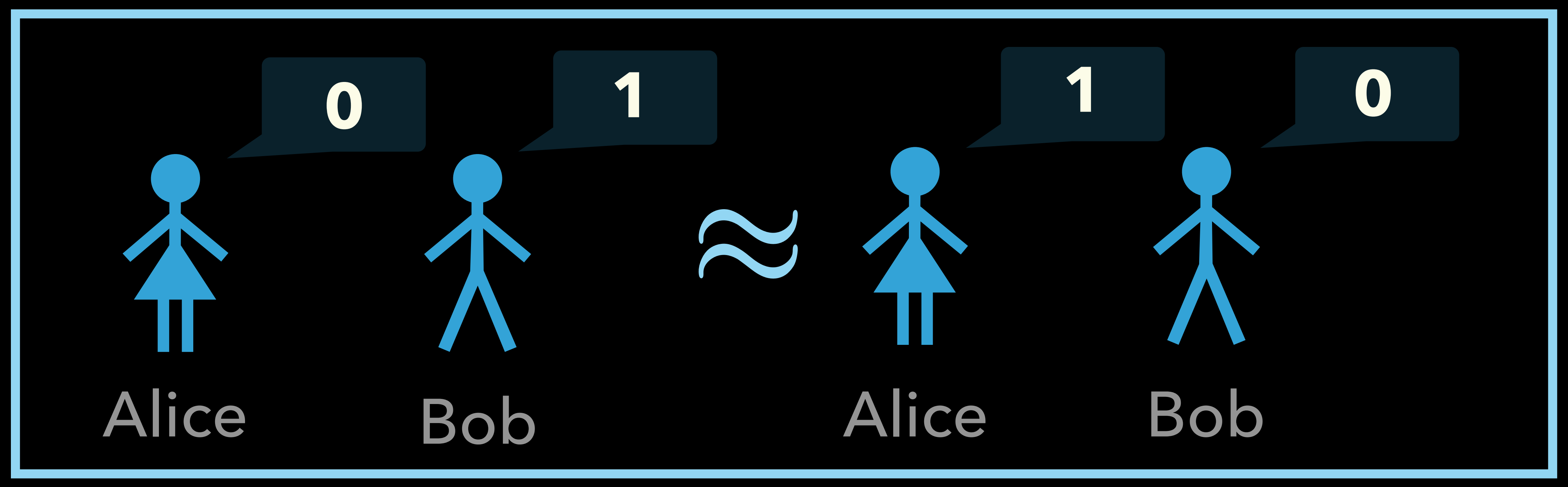

Vote privacy

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Future work

Speed-up of the procedure in practical cases by using symmetry reductions

CONCLUSION

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logical flaws of
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Exact Analysis
without approximations
+ full finite fragment

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"Optimal" Complexity
coNEXP-hardness
of the problem

Conclusion

Implementation

available at

https://deepsec-prover.github.io

logical flaws of
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coNEXP-hardness
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