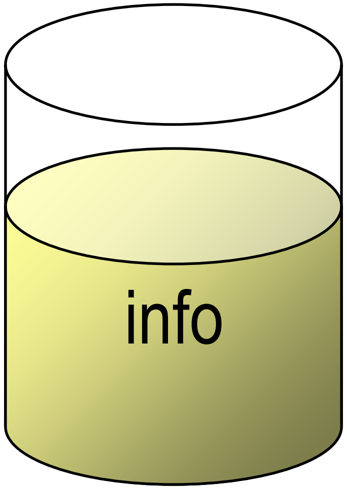
Course outline: the four hours

1. Language-Based Security: motivation
2. Language-Based Information-Flow Security: the big picture
3. Dimensions and principles of declassification
4. Dynamic vs. static security enforcement

Dimensions of Declassification in Theory and Practice

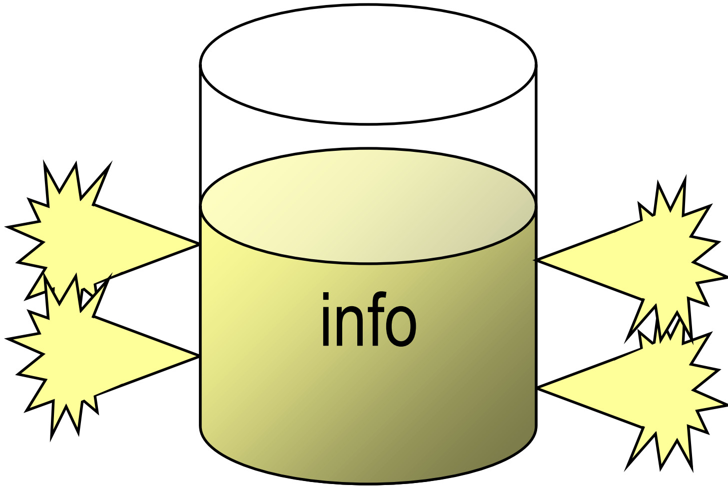
Confidentiality: preventing information leaks

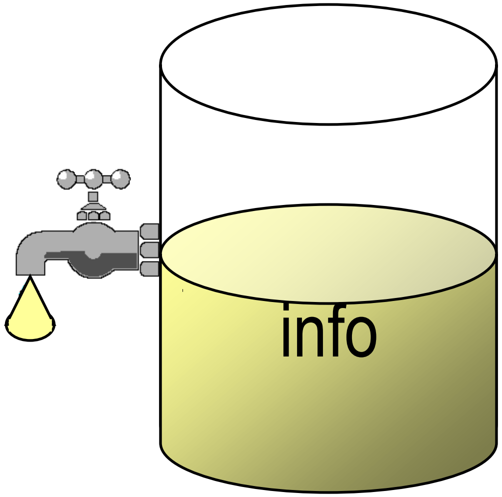


- Untrusted/buggy code should not leak sensitive information
- But some applications depend on intended information leaks
  - password checking
  - information purchase
  - spreadsheet computation
  - ...
- Some leaks must be allowed: need information release (or declassification)

Confidentiality vs. intended leaks

- Allowing leaks might compromise confidentiality
- Noninterference is violated
- How do we know secrets are not laundered via release mechanisms?
- Need for security assurance for programs with release

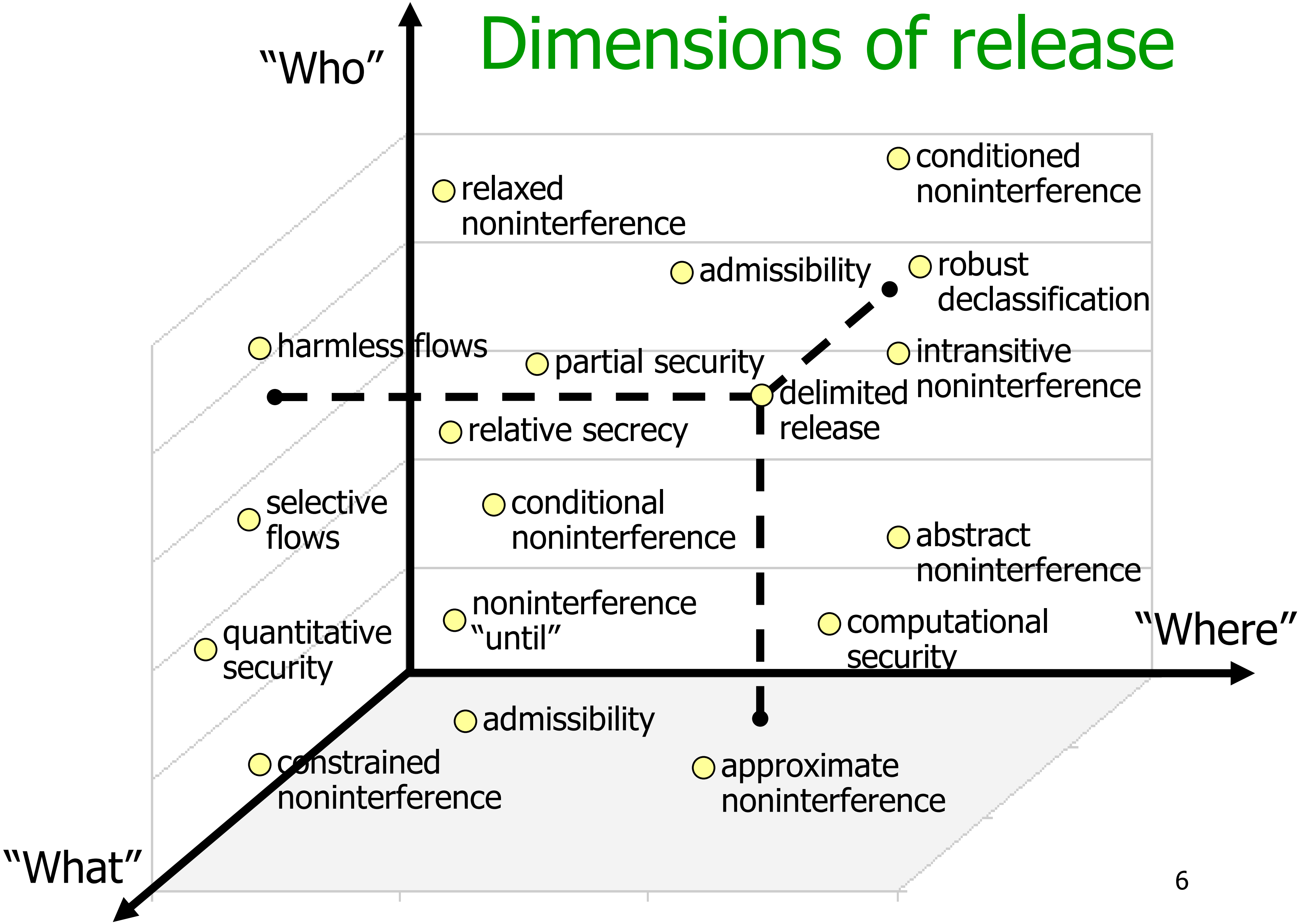




State-of-the-art

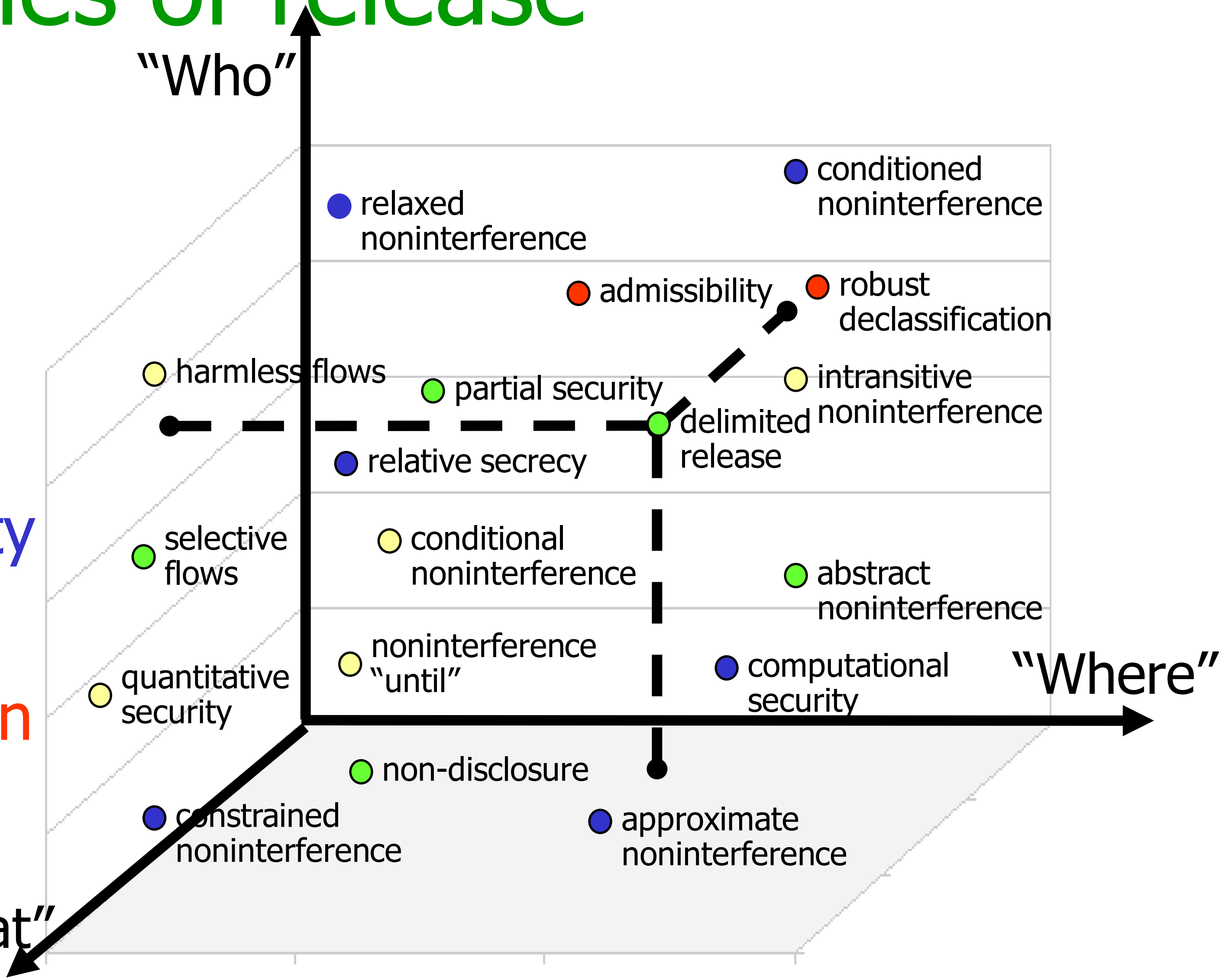
- relaxed noninterference
- conditioned noninterference
- admissibility
- robust declassification
- harmless flows
- intransitive noninterference
- partial security
- delimited release
- relative secrecy
- selective flows
- conditional noninterference
- abstract noninterference
- noninterference “until”
- computational security
- quantitative security
- admissibility
- constrained noninterference
- approximate noninterference

Dimensions of release



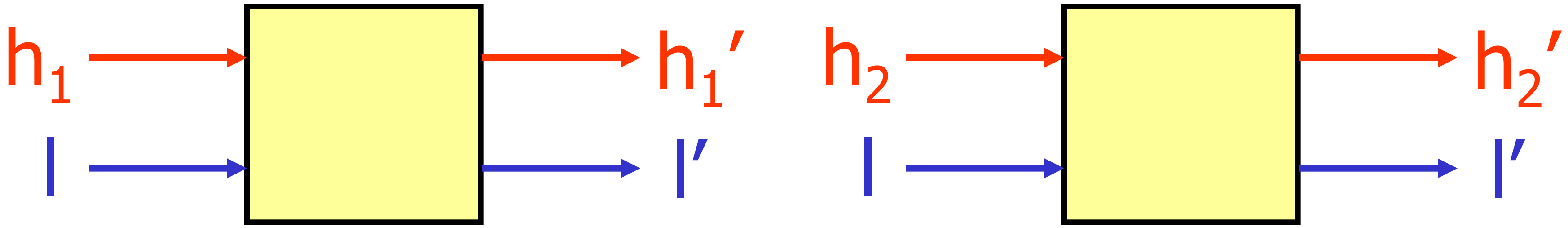
Principles of release

- Semantic consistency
- Conservativity
- Monotonicity
- Non-occlusion



What

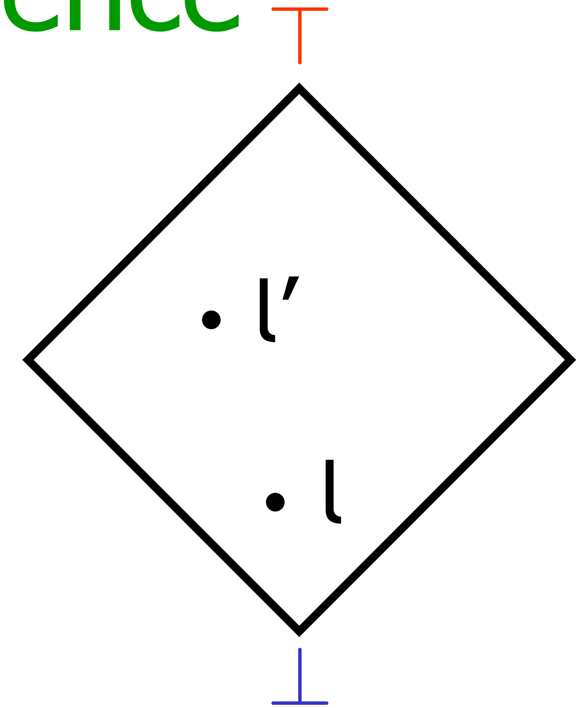
- Noninterference [Goguen & Meseguer]: as high input varied, low-level outputs unchanged



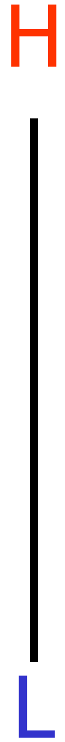
- Selective (partial) flow
  - Noninterference within high sub-domains [Cohen’78, Joshi & Leino’00]
  - Equivalence-relations view [Sabelfeld & Sands’01]
  - Abstract noninterference [Giacobazzi & Mastroeni’04,’05]
  - Delimited release [Sabelfeld & Myers’04]
- Quantitative information flow [Denning’82, Clark et al.’02, Lowe’02]

Security lattice and noninterference

Security lattice:



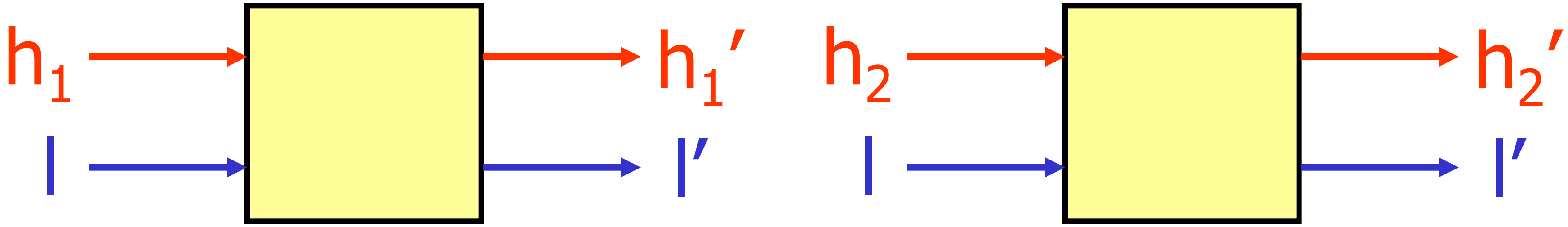
e.g.:



Noninterference: flow from l to l' allowed when $l \sqsubseteq l'$

Noninterference

- Noninterference [Goguen & Meseguer]: as high input varied, low-level outputs unchanged



- Language-based noninterference for c:

$$M_1 =_L M_2 \;\&\; \langle M_1,c\rangle \Downarrow M'_1 \;\&\; \langle M_2,c\rangle \Downarrow M'_2 \Rightarrow M'_1 =_L M'_2$$

Low-memory equality:
$M_1 =_L M_2$ iff $M_1|_L = M_2|_L$

Configuration with M_2 and c

Average salary

- Intention: release average

`avg:=declassify((h1+...+hn)/n,low);`

- Flatly rejected by noninterference
- If accepting, how do we know declassify does not release more than intended?
- Essence of the problem: what is released?
- "Only declassified data and no further information"
- Expressions under declassify: "escape hatches"

Delimited release

[Sabelfeld & Myers, ISSS’03]

- Command c has expressions declassify(e_i,L); c is secure if:

if M_1 and M_2 are indistinguishable through all e_i…

$$M_1 =_L M_2 \ \& \ \langle M_1,c\rangle \Downarrow M'_1 \ \& \ \langle M_2,c\rangle \Downarrow M'_2 \ \& \\ \forall i\ .\mathrm{eval}(M_1,e_i)=\mathrm{eval}(M_2,e_i) \Rightarrow \\ M'_1 =_L M'_2$$

…then the entire program may not distinguish M_1 and M_2

$\Rightarrow$ security

- For programs with no declassification:
  Security $\Rightarrow$ noninterference

Average salary revisited

- Accepted by delimited release:

$\mathrm{avg}:=\mathrm{declassify}((h_1+\ldots+h_n)/n,\mathrm{low});$

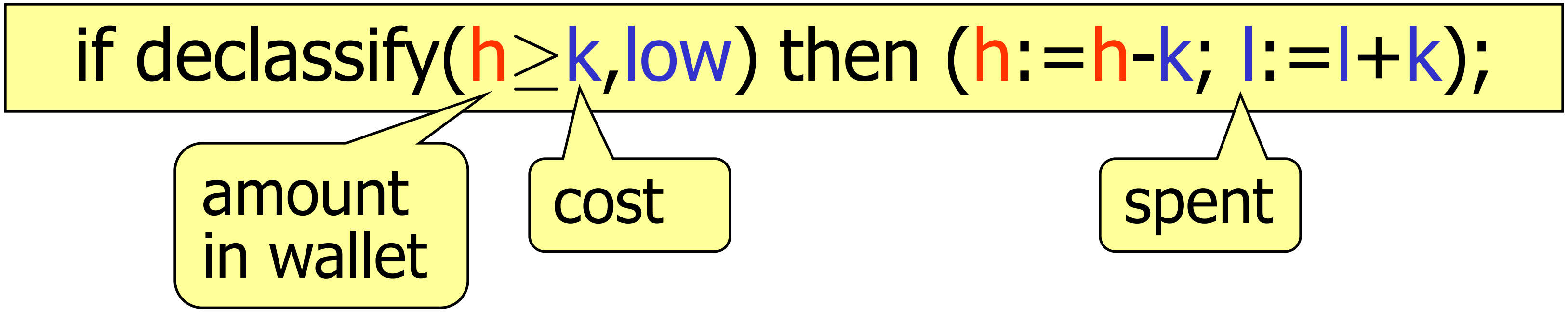
$\mathrm{temp}:=h_1;\ h_1:=h_2;\ h_2:=\mathrm{temp};$
$\mathrm{avg}:=\mathrm{declassify}((h_1+\ldots+h_n)/n,\mathrm{low});$

- Laundering attack rejected:

$$\begin{array}{c} h_2:=h_1;\ldots;\ h_n:=h_1; \\ \mathrm{avg}:=\mathrm{declassify}((h_1+\ldots+h_n)/n,\mathrm{low}); \end{array} \sim \boxed{\mathrm{avg}:=h_1}$$

Electronic wallet

- If enough money then purchase



```
if declassify(h≥k,low) then (h:=h-k; l:=l+k);
```

- Accepted by delimited release

Electronic wallet attack

- Laundering bit-by-bit attack (h is an n-bit integer)

```
l:=0;
while($n \geq 0$) do
    k:=$2^{n-1}$;
    if declassify($h \geq k$,low)
        then (h:=h-k; l:=l+k);
    n:=n-1;
```

$\sim$

```
l:=h
```

- Rejected by delimited release

Security type system

- Basic idea: prevent new information from flowing into variables used in escape hatch expressions

```
h:=…;
…
declassify(h,low)
```

may not use other (than h) high variables

```
while … do
  declassify(h,low)
  …
  h:=…;
```

may not use other (than h) high variables

- Theorem:
  c is typable ⇒ c is secure

Who

- Robust declassification in a language setting [Myers, Sabelfeld & Zdancewic'04/06]
- Command c[•] has robustness if

$$\forall M_1,M_2,a,a'.\ \langle M_1,c[a]\rangle \approx_L \langle M_2,c[a]\rangle \Rightarrow \langle M_1,c[a']\rangle \approx_L \langle M_2,c[a']\rangle$$

attacks

- If a cannot distinguish bet. M_1 and M_2 through c then no other a' can distinguish bet. M_1 and M_2

Robust declassification: examples

- Flatly rejected by noninterference, but secure programs satisfy robustness:

[•]; x_{LH}:=declassify(y_{HH},LH)

[•]; if x_{LH} then
y_{LH}:=declassify(z_{HH},LH)

- Insecure program:

[•]; if x_{LL} then y_{LL}:=declassify(z_{HH},LH)

is rejected by robustness

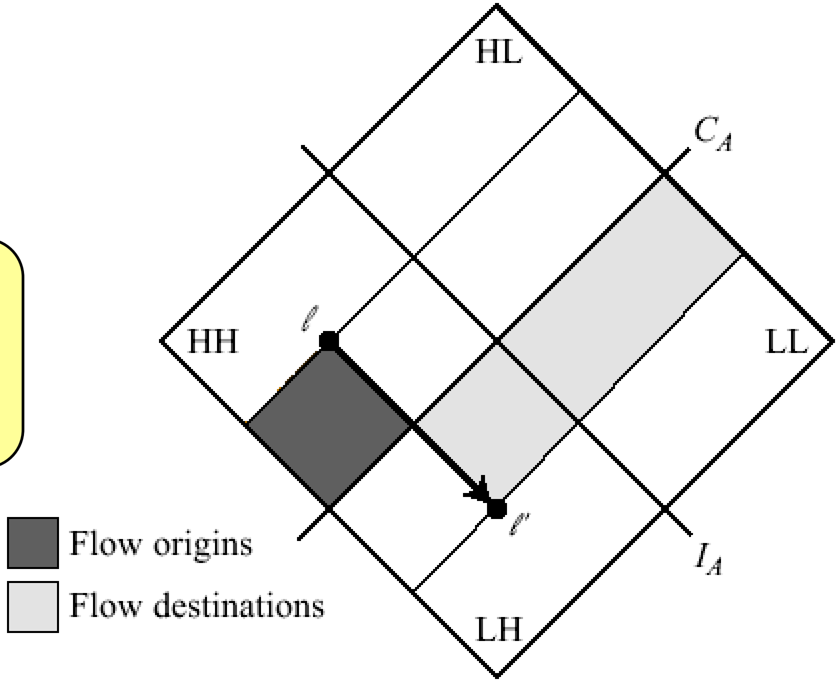
Enforcing robustness

- Security typing for declassification:

context must be high-integrity

data must be high-integrity

$$\frac{LH \vdash e : HH}{LH \vdash \mathrm{declassify}(e, l') : LH}$$



Where

- Intransitive (non)interference
  - assurance for intransitive flow [Rushby’92, Pinsky’95, Roscoe & Goldsmith’99]
  - nondeterministic systems [Mantel’01]
  - concurrent systems [Mantel & Sands’04]
  - to be declassified data must pass a downgrader [Ryan & Schneider’99, Mullins’00, Dam & Giambiagi’00, Bossi et al.’04, Echahed & Prost’05, Almeida Matos & Boudol’05]

When

- Time-complexity based attacker
  - password matching [Volpano & Smith’00] and one-way functions [Volpano’00]
  - poly-time process calculi [Lincoln et al.’98, Mitchell’01]
  - impact on encryption [Laud’01,’03]
- Probabilistic attacker [DiPierro et al.’02, Backes & Pfitzmann’03]
- Relative: specification-bound attacker [Dam & Giambiagi’00,’03]
- Non-interference “until” [Chong & Myers’04]

Principle I

Semantic consistency

The (in)security of a program is invariant under semantics-preserving transformations of declassification-free subprograms

- Aid in modular design
- "What" definitions generally semantically consistent
- Uncovers semantic anomalies

Principle II

Conservativity

Security for programs with no declassification is equivalent to noninterference

- Straightforward to enforce (by definition); nevertheless:
- Noninterference "until" rejects

```
if h>h then l:=0
```

Principle III

Monotonicity of release

Adding further declassifications to a secure program cannot render it insecure

- Or, equivalently, an insecure program cannot be made secure by *removing* declassification annotations
- “Where”: intransitive noninterference (a la M&S) fails it; declassification actions are observable

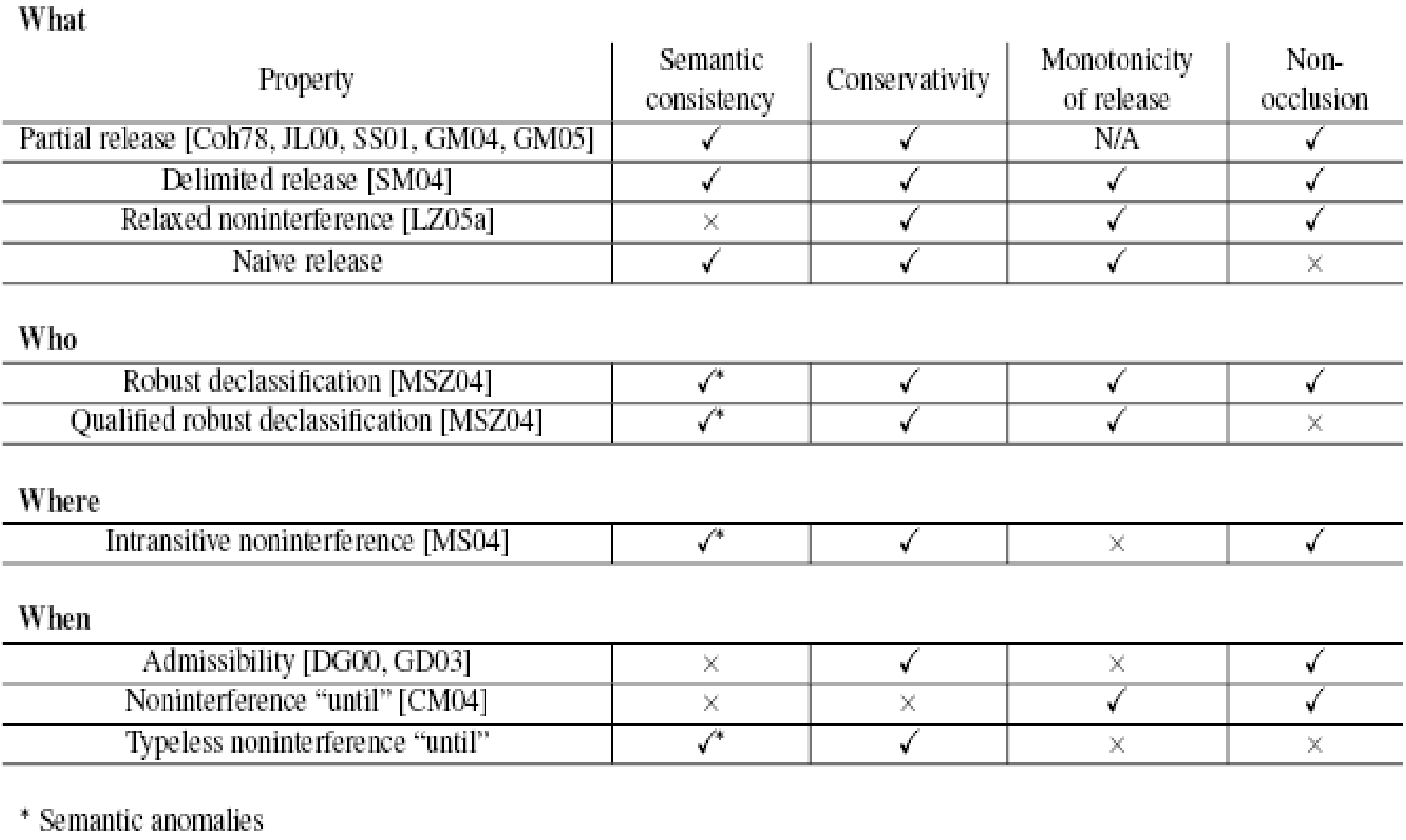
```
if h then declassify(l=l) else l=l
```

Principle IV

Occlusion

The presence of a declassification operation cannot mask other covert declassifications

Checking the principles



What

Property	Semantic consistency	Conservativity	Monotonicity of release	Non-occlusion
Partial release [Coh78, JL00, SS01, GM04, GM05]	✓	✓	N/A	✓
Delimited release [SM04]	✓	✓	✓	✓
Relaxed noninterference [LZ05a]	×	✓	✓	✓
Naive release	✓	✓	✓	×

Who

Robust declassification [MSZ04]	✓*	✓	✓	✓
Qualified robust declassification [MSZ04]	✓*	✓	✓	×

Where

Intransitive noninterference [MS04]	✓*	✓	×	✓

When

Admissibility [DG00, GD03]	×	✓	×	✓
Noninterference “until” [CM04]	×	×	✓	✓
Typeless noninterference “until”	✓*	✓	×	×

* Semantic anomalies

Declassification in practice: A case study

[Askarov & Sabelfeld, ESORICS'05]

- Use of security-typed languages for implementation of crypto protocols
- Mental Poker protocol by [Roca et.al, 2003]
  - Environment of mutual distrust
  - Efficient

- Jif language [Myers et al., 1999-2005]
  - Java extension with security types
  - Decentralized Label Model
  - Support for declassification

- Largest code written in security-typed language up to publ date [~4500 LOC]

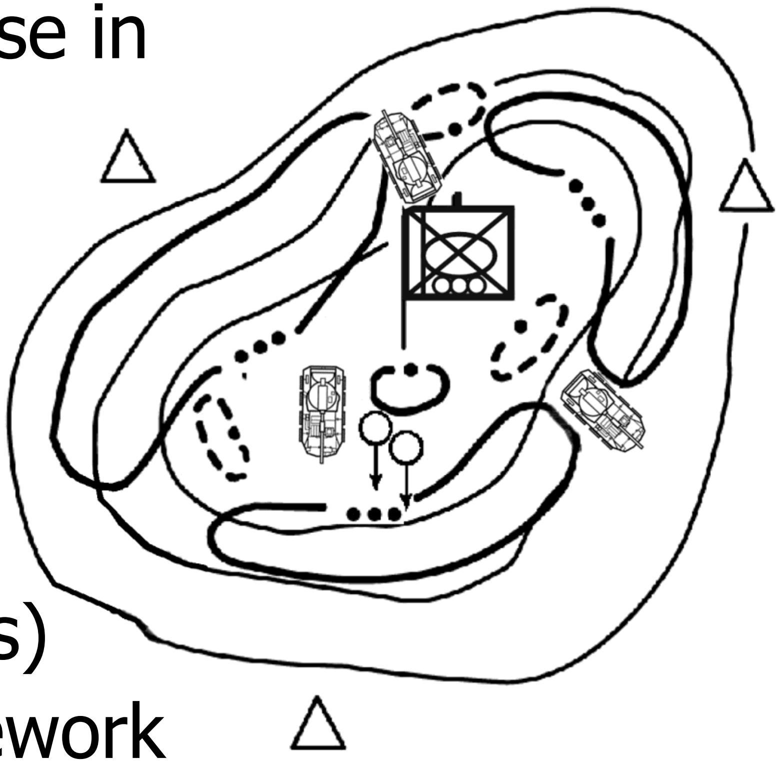
Security assurance/Declassification

Group	Pt.	What	Who	Where
I	1	Public key for signature	Anyone	Initialization
	2	Public security parameter	Player	Initialization
II	3	Message signature	Player	Sending msg
	4-7	Protocol initialization data	Player	Initialization
	8-10	Encrypted permuted card	Player	Card drawing
III	11	Decryption flag	Player	Card drawing
IV	12-13	Player’s secret encryption key	Player	Verification
	14	Player’s secret permutation	Player	Verification

Group I – naturally public data Group II – required by crypto protocol

Group III – success flag pattern Group IV – revealing keys for verification

Dimensions: Conclusion



- Road map of information release in programs
- Step towards policy perimeter defense: to protect along each dimension
- Prudent principles of declassification (uncovering previously unnoticed anomalies)
- Need for declassification framework for relation and combination along the dimensions

References

- Declassification: Dimensions and Principles
  [Sabelfeld & Sands, JCS]