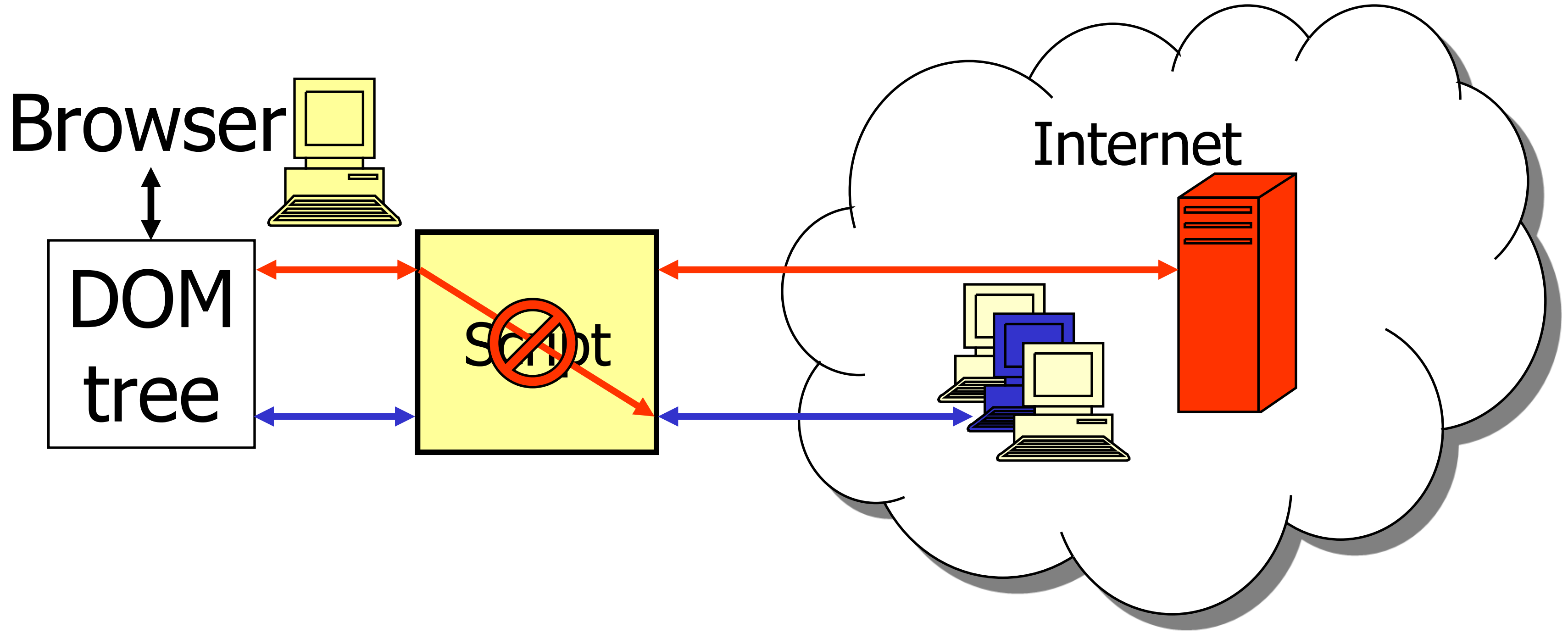
Course outline: the four hours

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

From dynamic to static and back

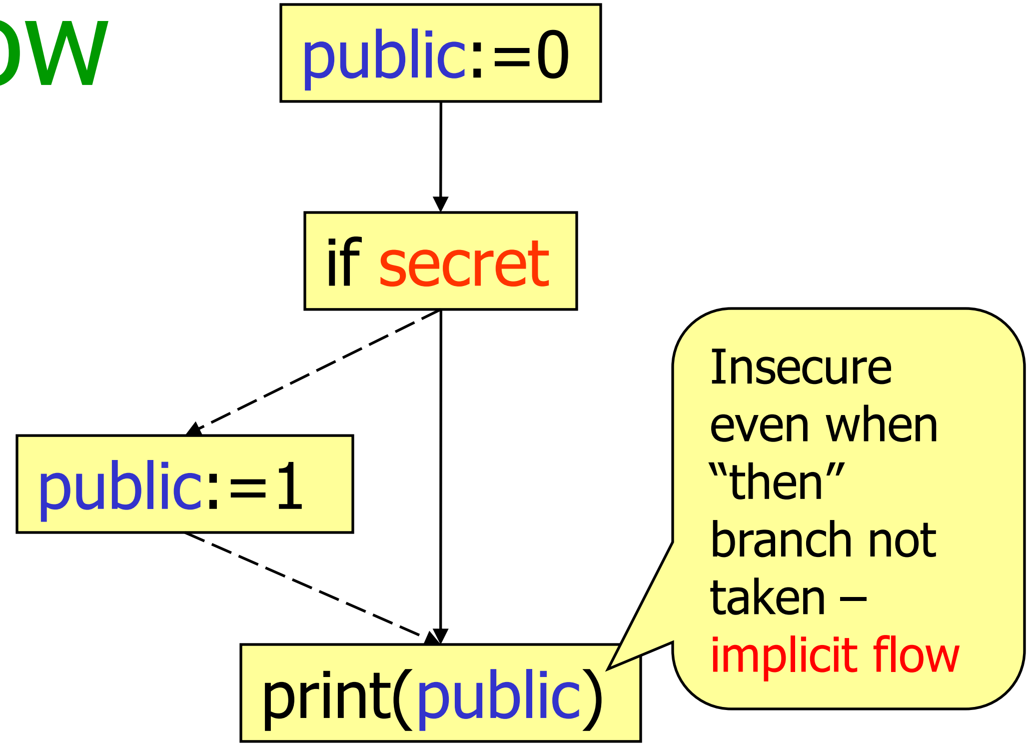
Riding the roller coaster of information-flow control research

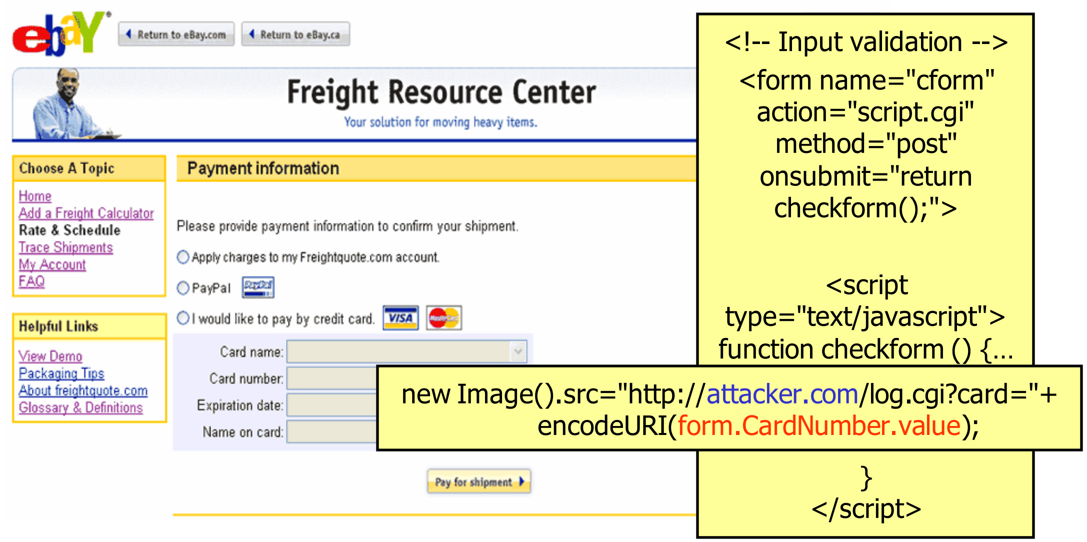
Information flow controls



Information flow problem

- Studied in 70's
  - military systems
- Revival in 90's
  - mobile code
- Hot topic in language-based security in 00's
  - web application security





Information flow in 70’s

- Runtime monitoring
  - Fenton’s data mark machine
  - Gat and Saal’s enforcement
  - Jones and Lipton’s surveillance
- Dynamic invariant: ”No public side effects in secret context”
- Formal security arguments lacking

Denning’s static certification

- Static check: ”No public side effects in secret context”
  - Denning proposes 1977
  - Volpano, Smith & Irvine prove soundness 1996
  - no runtime overhead
- Core of modern tools
  - Jif/Sif/SWIFT (Java)
  - SparkAda (Ada)
  - FlowCaml (Caml)

Static the way to go?

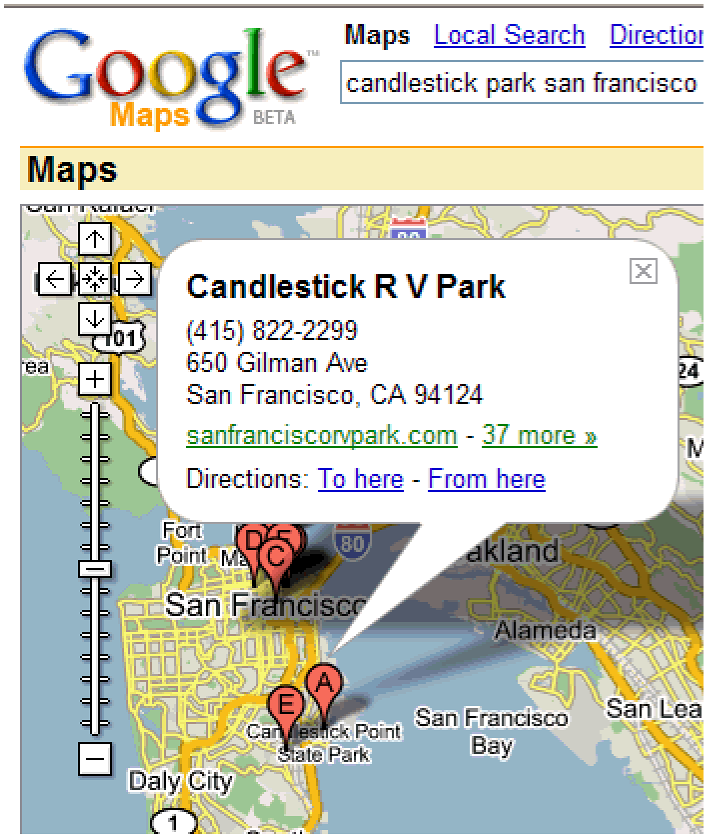
- Domination of static information flow control in 90’s
  - confirmed by survey [Sabelfeld & Myers’03]
- A sample citation from 90’s:

  "*…static checking allows precise, fine-grained analysis of information flows, and can capture implicit flows properly, whereas dynamic label checks create information channels that must be controlled through additional static checking…*”

- Common wisdom:
  - monitoring a single path misses public side effects that could have happened
- RIP dynamic enforcement?

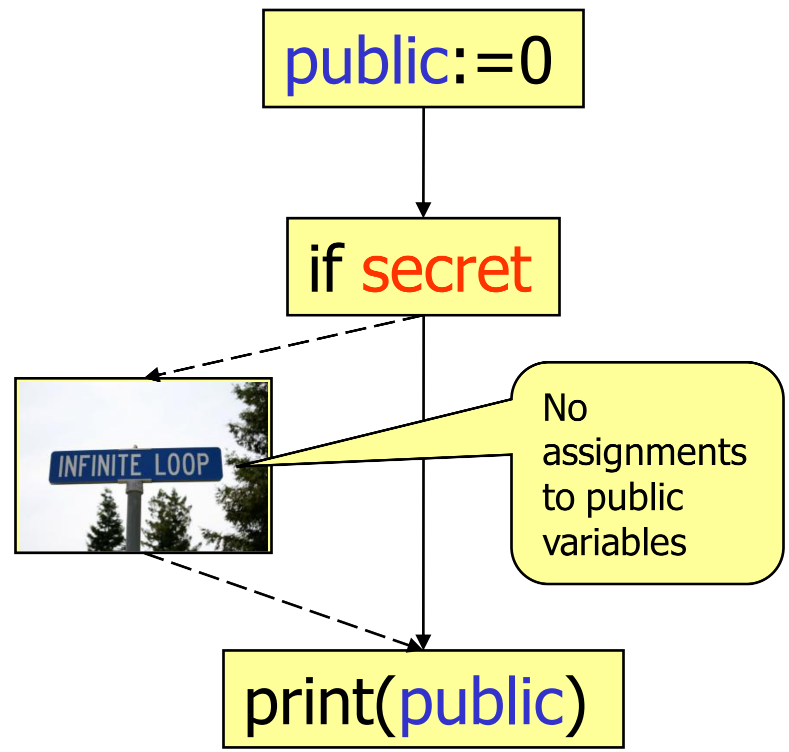
What about interactive (e.g. web) applications

- Code (downloaded and) evaluated depending on user's input
  - Common technique for web applications
  - Google maps
- Monitoring this without "additional static checking" breaks security?



No! In fact, dynamic enforcement is as secure as Denning-style enforcement

- Trick: termination channel
- Denning-style enforcement termination-insensitive
- Monitor blocks execution before a public side effect takes place in secret context



Modular enforcement

Program

$cfg \xrightarrow{\beta} cfg'$

skip

x:=e

;

if…, while…

Actions β

s

a(x,e)

b(e)

f

Monitor

$cfgm \xrightarrow{\beta} cfgm'$

Termination-insensitive monitor

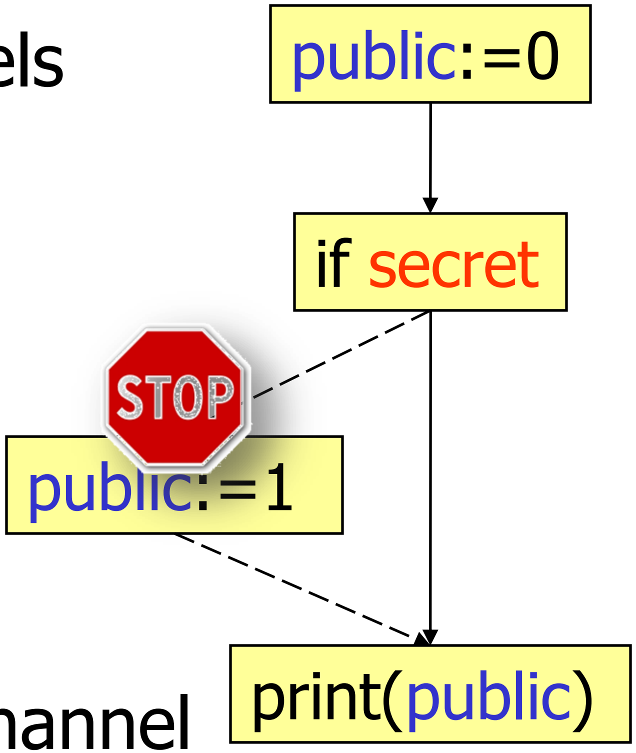
- cfgm=st
- prevent explicit flows l:=h
- prevent implicit flows if h then l:=0
  - by dynamic pc = highest level on context stack

stack of security contexts

Action	Monitor's reaction	
	stop if	stack update
a(x,e)	x and (e or pc)	
b(e)		push(lev(e))
f		pop

Dynamic enforcement collapses flow channels into termination channel

- Otherwise high-bandwidth channels
  - Implicit flows
  - Exceptions
  - Declassification
    - [Askarov & Sabelfeld'09]
  - DOM tree operations
    - [Russo, Sabelfeld & Chudnov'09]
  - Timeouts
    - [Russo & Sabelfeld'09]
- … all collapsed into termination channel
- security guarantees apply



Security implications

Termination-insensitive security implies

- For language without I/O: at most one bit leak per execution
- For language with I/O [Askarov, Hunt, Sabelfeld & Sands'08]:
  - attacker cannot learn secret in poly time (in the size of the secret)
  - attacker's advantage for guessing the secret after observing output for poly time is negligible

Results

- Denning-style analysis enforces termination-insensitive security
  - for while language [Volpano, Smith & Irvine'96]
  - for language with I/O [Askarov, Hunt, Sabelfeld & Sands'08]
- Dynamic enforcement more permissive than static
  - Typable programs not blocked by monitor
  - l:=l*l; if l<0 then l:=h
- Monitoring enforces termination-insensitive security
  - for while language
  - for language with I/O

Flow sensitivity

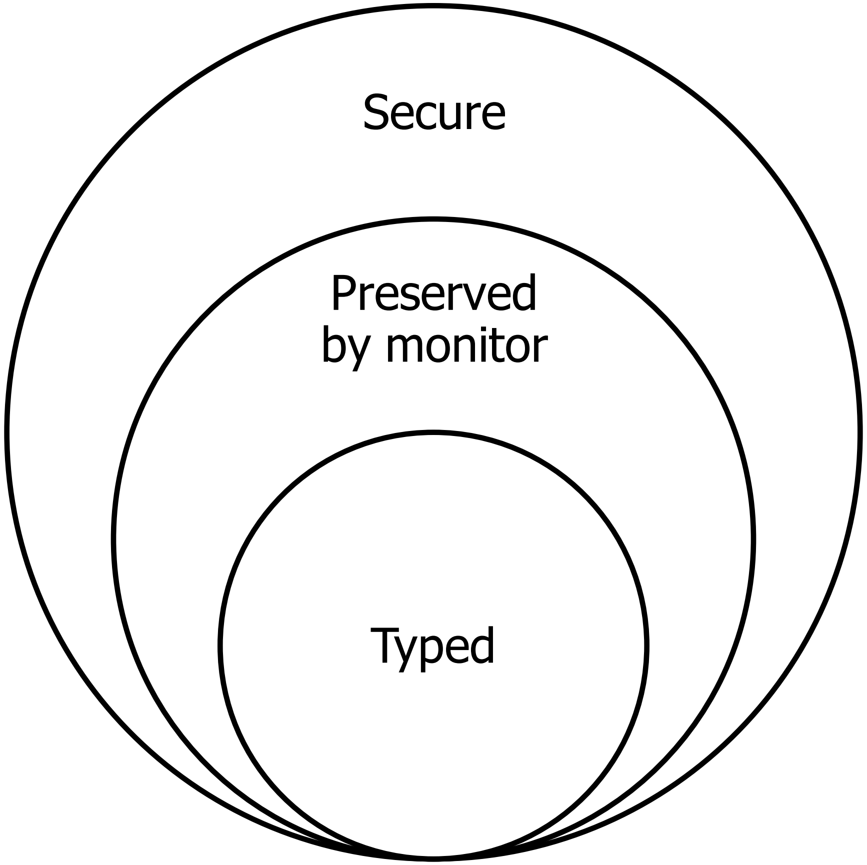
- Flow-insensitive analyses in this talk so far

```
secret := 0;
if secret then public := 1
```

- Rejected by flow-insensitive analysis
- Flow sensitive analysis relabels secret when it is assigned public constant
  - E.g. [Hunt & Sands'06]
- Particularly useful for low-level languages
  - secure register reuse

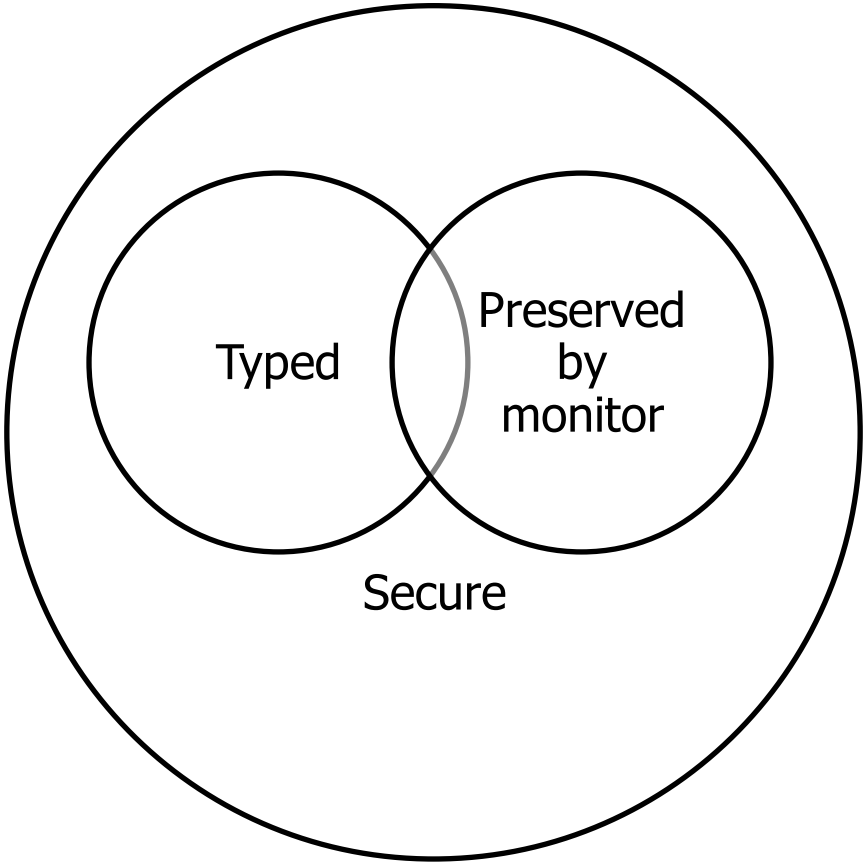
Not all channels can be collapsed into termination channel

- Can we generalize the results to flow-sensitive case?
- Intuition: even more dynamism with flow-sensitivity so we should gain in precision



Flow sensitivity: Turns out

- Can have sound or permissive analysis but not both
- Theorem: no purely dynamic permissive and sound monitor



Trade off between permissiveness and soundness

```
public := 1; temp := 0;
if secret then temp := 1;
if temp != 1 then public := 0
```

- Purely dynamic monitor needs to make a decision about temp
- Impossible to make a correct decision without sacrificing permissiveness

Proof sketch I

- If secret is true, we can type:

```
public := 1; temp := 0;
if secret then temp := 1;
if temp != 1 then ~~public := 0~~ skip;
output(public)
```

- By permissiveness, it should be accepted by monitor
- By dynamism, original program also accepted by monitor

```
public := 1; temp := 0;
if secret then temp := 1;
if temp != 1 then public := 0;
output(public)
```

Proof sketch II

- If secret is false, we can type:

```
public := 1; temp := 0;
if secret then ~~temp := 1~~ skip;
if temp != 1 then public := 0;
output(public)
```

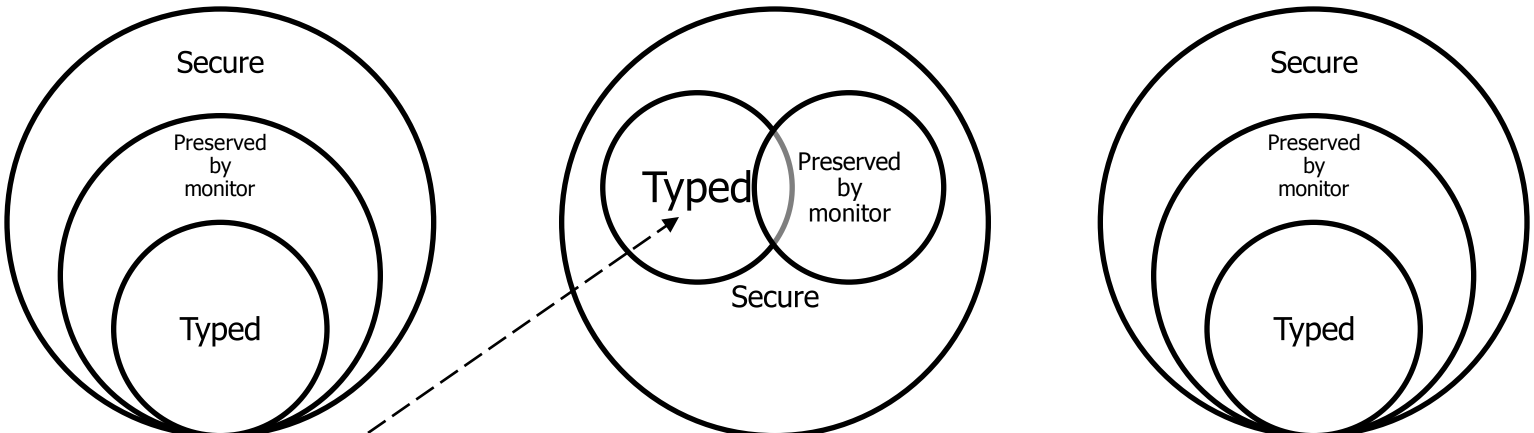
- By permissiveness, it should be accepted by the monitor
- By dynamism, original program also accepted by monitor

```
public := 1; temp := 0;
if secret then temp := 1;
if temp != 1 then public := 0;
output(public)
```

- => Insecure program always accepted by monitor
- Can have sound or permissive purely dynamic monitor but not both

Static vs. dynamic

- Fundamental trade offs between dynamic and static analyses



Flow-insensitive analysis | Flow-sensitive analysis | Flow-sensitive analysis, hybrid monitors

- Case studies to determine practical consequences

Going dynamic

- Dynamic analysis viable option for dynamic (esp. web) applications
  - fit for interactive applications with dynamic code evaluation
  - more permissive than Denning-style analysis
  - as secure as Denning-style analysis, despite common wisdom
- Dynamic security enforcement increasingly active area
- Opening up for exciting synergies

References

- From dynamic to static and back: Riding the roller coaster of information-flow control research [Sabelfeld & Russo, PSI'09]
- Tight enforcement of information-release policies for dynamic languages [Askarov & Sabelfeld, CSF'09]

Course summary

- Language-based security
  - from off-beat ideas to mainstream technology in just a few years
  - high potential for web-application security
- Declassification
  - dimensions and principles
  - combining dimensions key to security policies
- Enforcement
  - type-based for "traditional languages"
  - dynamic and hybrid for dynamic languages