Practical Mostly-Static Information Flow Control

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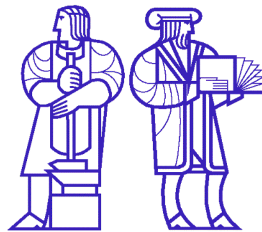
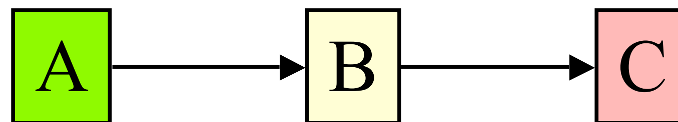
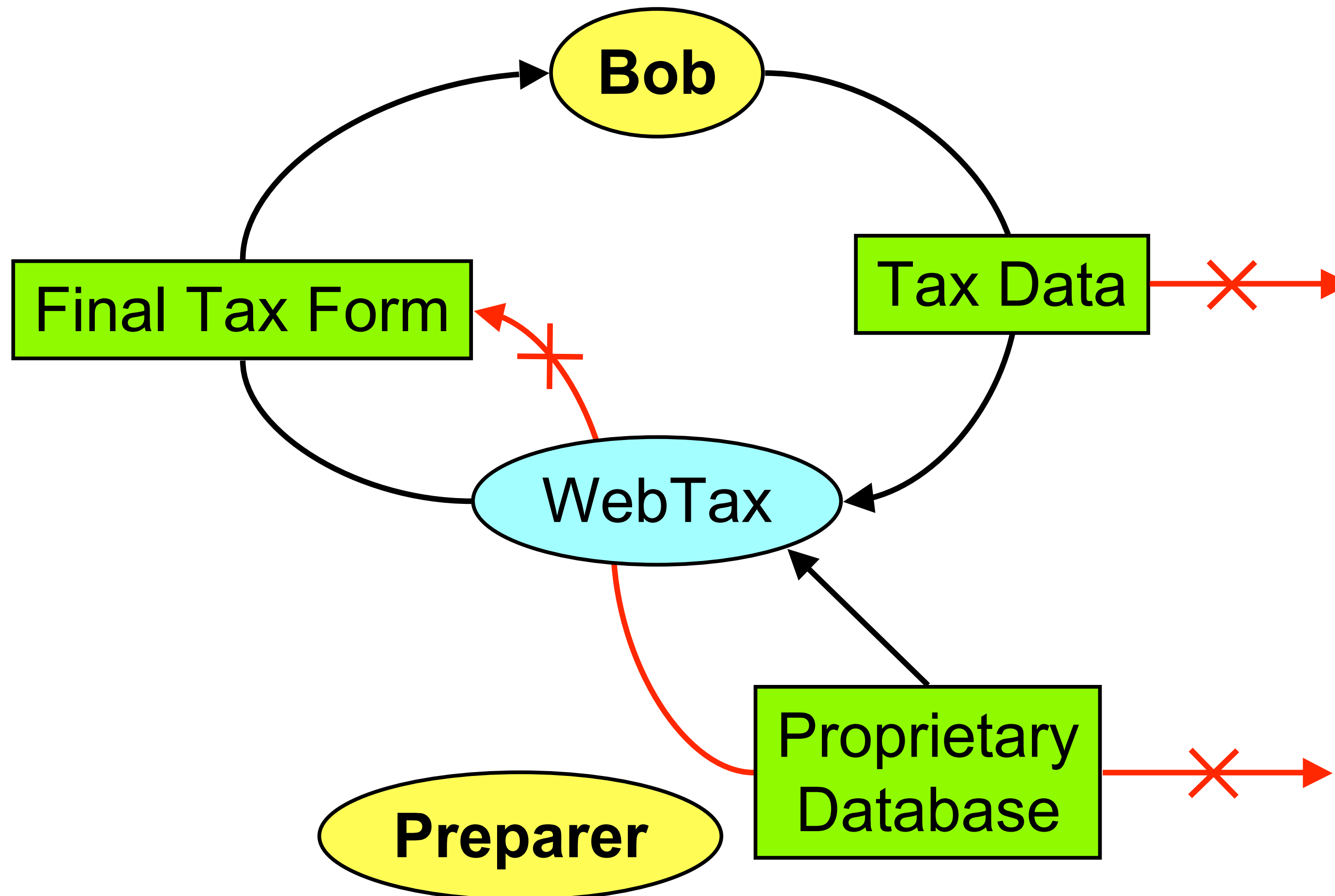


Privacy

- Old problem (secrecy, confidentiality) : prevent programs from leaking data
- Untrusted, downloaded code: more important
- Standard security mechanisms not effective (*e.g.*, access control)



Privacy with Mutual Distrust



Static Information Flow

- Denning & Denning ’77
- Programs must follow rules
- Annotations added for tractability
- Static analysis = type checking
- Security property composes

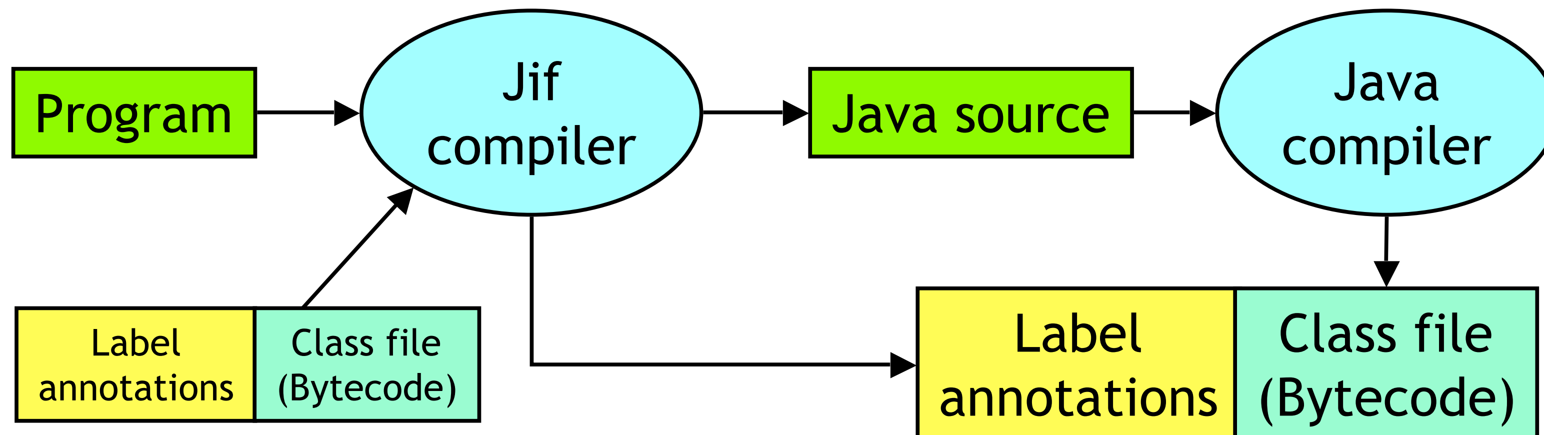
A	+	B	=	A	B

Jif Language

- Jif = Java + information flow annotations (Java Information Flow)
- More practical than previous work
  - Real language: supports Java features
  - Convenience: automatic label inference
  - Genericity: label polymorphism
  - Decentralized declassification mechanism
  - Run-time label checking

Architecture

- Source to source translator (mostly erasure)
- Modification to the **PolyJ** compiler (Java + parametric polymorphism)



Jif Features

- Labeled types
- Convenience: automatic label inference
- Genericity: label polymorphism
- Static, decentralized declassification
- Safe run-time label checking (first-class labels)
- First-class principals
- Object-oriented features
  - Subtyping rules
  - Inheritance
  - Constructors
  - Method constraints
- Exceptions
- Arrays
- Described by formal inference rules

Labeled Types

- Variables, expressions have *labeled type* $T\{L\}$
- Labels express privacy constraints
- L_2 is at least as restrictive as L_1: $L_1 \sqsubseteq L_2$
- Assignment rule (simplified)

$$\frac{v : T\{L_v\} \in A \quad A \vdash E : L_e \quad L_e \sqsubseteq L_v}{A \vdash v = E : L_e}$$

Decentralized Label Model

- Label is a set of policies
- Each policy is owner : reader_1 , reader_2 , ...
  - owner (principal)
  - set of readers (principals)

{ Bob : Bob, Preparer ; Preparer : Preparer }

- Every owner's policy is obeyed
- Relation $\sqsubseteq$ is pre-order w/lattice properties [ML98]

Implicit Label Polymorphism

- Method signatures contain labeled types

```
float {Bob: Bob} cos (float {Bob: Bob} x) {
   float {Bob: Bob} y = x – 2*PI*(int)(x/(2*PI));
   return 1 - y*y/2 + ...;
}
```

- Omitted argument labels: *implicit label polymorphism*

```
float{x} cos (float x) {
   float y = x – 2*PI*(int)(x/(2*PI));
   return 1 - y*y/2 + ...;
}
```

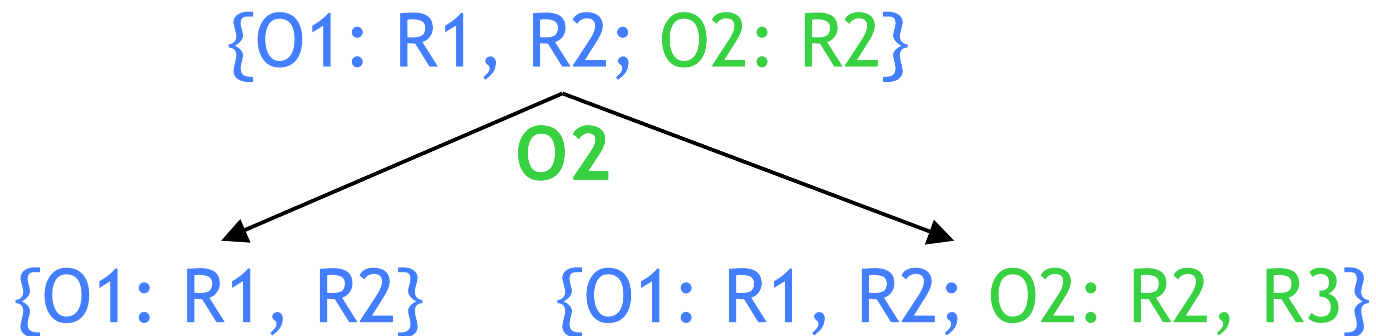
Explicit Parameterization

```
class Cell[label L] {
    private Object{L} y;
    public void store{L} ( Object{L} x ) { y = x; }
    public Object{L} fetch ( ) { return y; }
}
                    Cell[{Bob: Amy}]
```

- Straightforward analogy with type parameterization
- Allows generic collection classes
- Parameters not represented at run time

Declassification

- A principal can rewrite its part of the label



- Other owners' policies still respected
- Must know authority of running process
- Potentially dangerous: explicit operation

declassify(E, L)

Static Authority

- Authority of code is tracked statically

```
class C authority(root) {
    ...
}
```

- Authority propagated dynamically:

```
void m(principal p, int {root:} x) where caller(p) {
    actsFor(p, root) {
        int{} y = declassify(x, {}) // checked statically
    } else {
        // can't declassify x here
    }
}
```

Implicit Flows and Exceptions

- Implicit flow: information transferred through control structure
- Static program counter label (pc) that expression label always includes
- Fine-grained exception handling: pc transfers via exceptions, break, continue

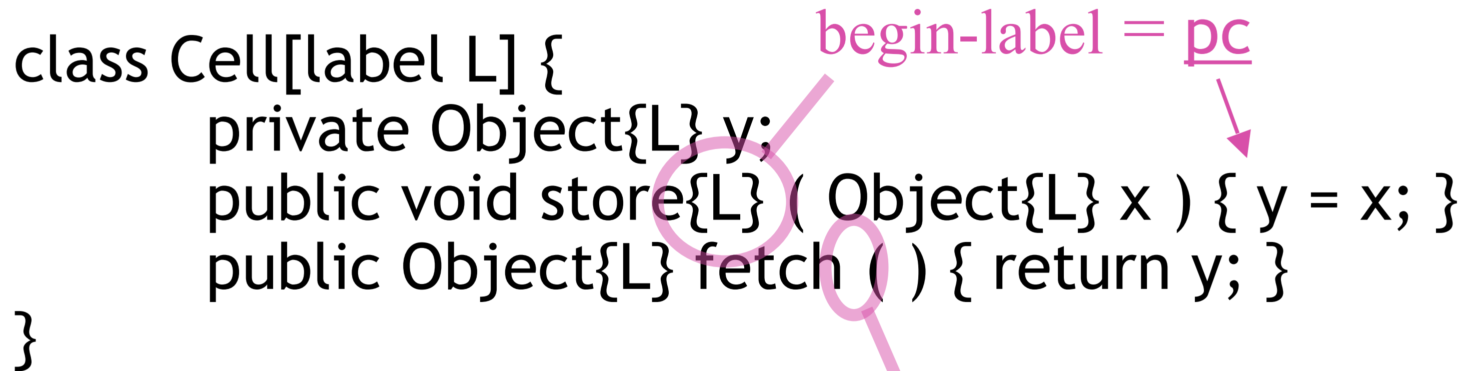
$\{b\} \sqsubseteq \{x\}$

```
x = b;
```

```
x = false;
if (b) {
   x = true;
}
```

```
x = false;
try {
   if (b) throw new Foo ();
} catch (Foo f) {
   x = true;
}
```

Methods and Implicit Flows



- Begin-label constrains calling pc : pc ⊑{L}
- Prevents implicit flow into method
- Omitted begin-label: implicit parameter, prevents mutation

Run-time Labels

- Labels may be first-class values, label other values:

```
final label a = ...;
int{*a} b;
```

- Run-time label treated statically like label parameter: unknown fixed label
- Exists at run time (`Jif.lang.Label`)
- `int{*a}` is dependent type

Run-time Label Discrimination

- switch label statement tests a run-time label dynamically:

```
final label a = ... ;
int{*a} b;
int { C: D } x;
switch label(b) {
   case ( int { C: D } b2 )  x = b2;
   else throw new BadLabelCast();
}
```

tests $a \sqsubseteq \{ C : D \}$ at run time

Run-time Labels and Implicit Flows

```
final label{b} a = b ? new label {L1} : new label {L2};
int{*a} dummy;
switch label(dummy) {
  case ({L1}) : x = true;
  case ({L2}) : x = false;
}
```

≡

```
x = b;
```

- Proper check is {b} ⊑ {x}
- In `case` clause, pc augmented with label *of* label `a` (which is {b})
- Therefore: `x = true` results in proper check

Implementation

- Translates to efficient Java, mostly by erasure
  - Labeled types become unlabeled types
  - Label parameters erased
- First-class label, principal values remain
- switch label, actsFor translated simply

Is it Practical yet?

- Addresses limitations of earlier approaches to checking information flow statically
  - allows run-time checking
  - infers annotations
  - limited declassification mechanism
  - genericity: implicit & explicit polymorphism
- Greater expressiveness and convenience
- Only small programs so far
- Can reuse existing Java code
- Only sequential programs, no timing channels

Related Work

Denning, Denning. CACM 1977

Palsberg, Ørbæk. ISSA 1995

Volpano, Smith, Irvine. JCS 1996

Myers, Liskov. SOSP 1997, IEEE S&P 1998

Heintze, Riecke. POPL 1998

Smith, Volpano. POPL 1998

Abadi, Banerjee, Heintze, Riecke. POPL 1999

Conclusions

- Most practical language yet for static enforcement of privacy
- Promising; more experience needed to understand limitations
- Why not 20 years ago?

Inheritance/Subtyping

C_2 ↑ C_1

- Subclass signature (1) constrained by superclass signature (2)
- Argument, begin-label a : $\{ a_2 \} \sqsubseteq \{ a_1 \}$
- Return value, exception r : $\{ r_1 \} \sqsubseteq \{ r_2 \}$
- Class authority (set of principals) can only increase with inheritance : $A_1 \supseteq A_2$