Complete, Safe Information Flow with Decentralized Labels

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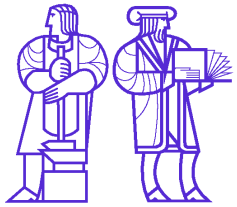
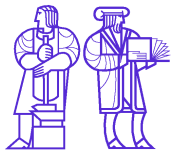
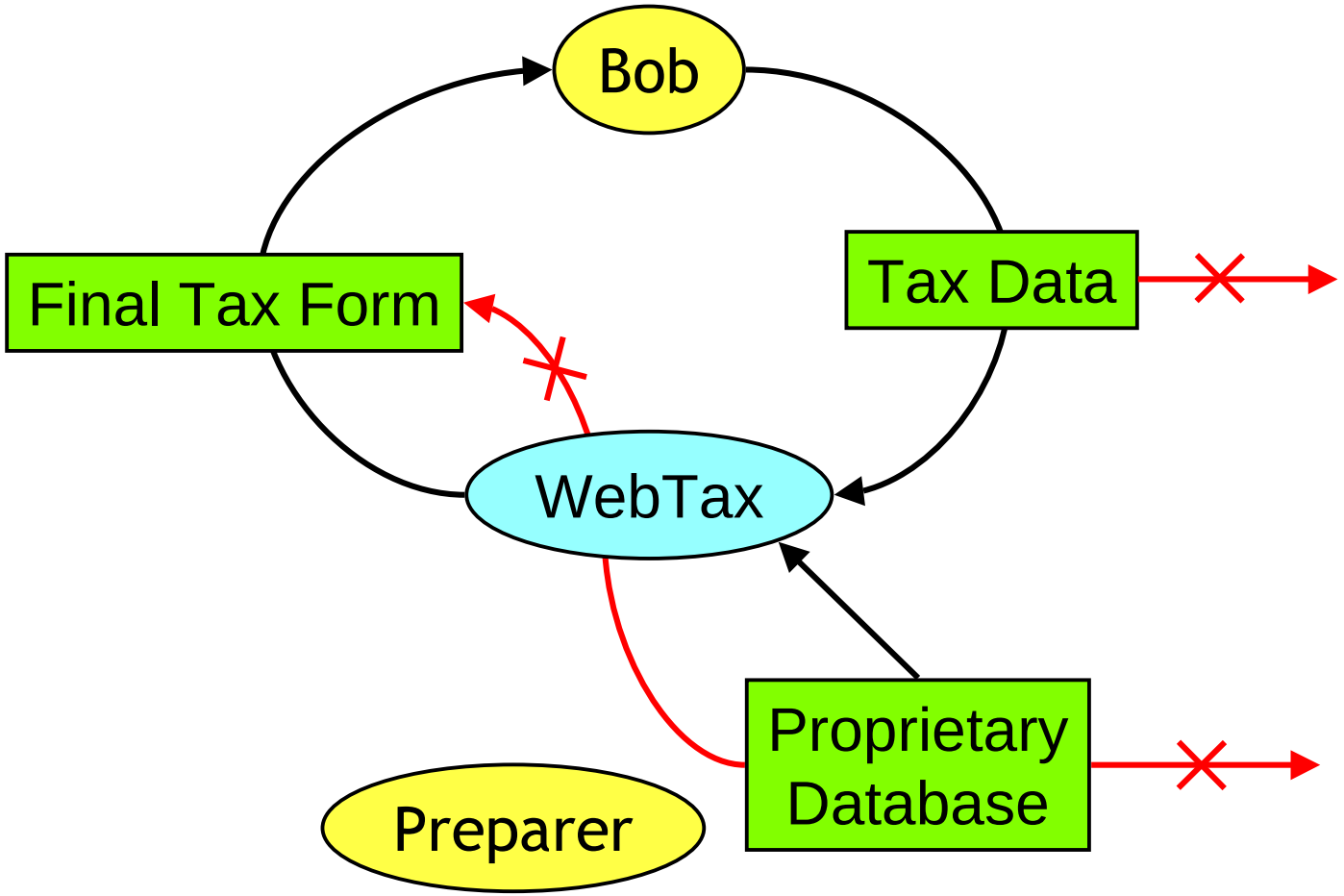


Protecting Private Data

- Goal:
  - prevent leaks of private data
  - allow cooperative data sharing
- Technique: statically analyze information flow in programs
  - correctly prevent storage channel leaks
  - good performance
- Implemented Java extension: **JFlow**

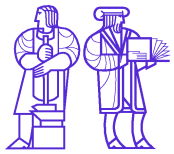


Sharing with Mutual Distrust



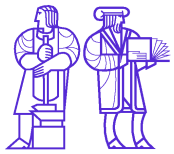
Decentralized Label Model

- Privacy of multiple principals with mutual distrust: decentralized
- Safe declassification within model
- Static checking: good performance



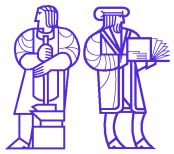
Outline

- Decentralized label model, rules
- Static checking & inference
- Soundness & completeness



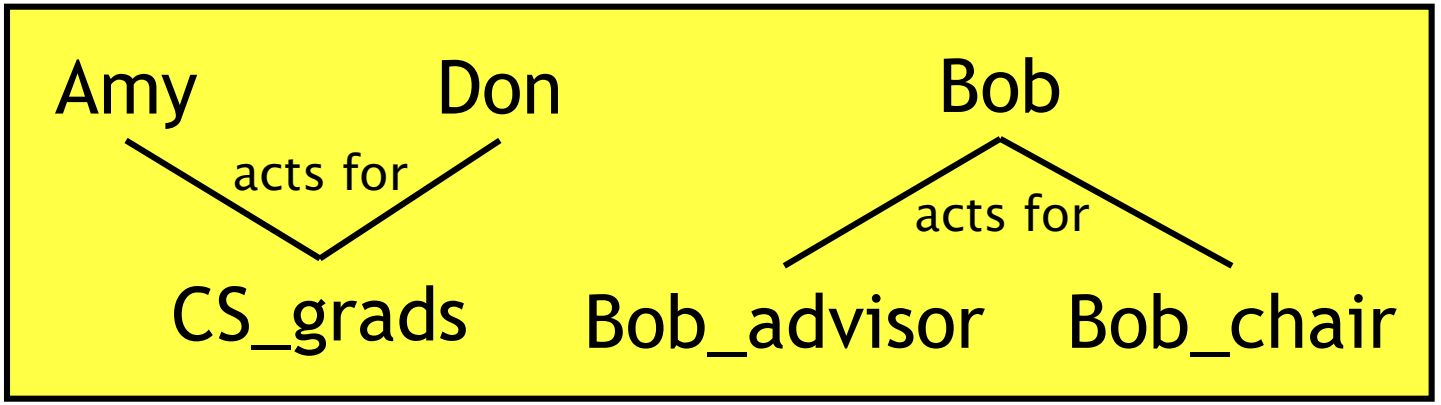
Model

- Principals
- Labels
- Program rules
  - Assignment
  - Computation
  - Declassification



Principals

- Users, groups, and roles: principals
- Principal hierarchy generated by the acts-for relation ($\succcurlyeq$):

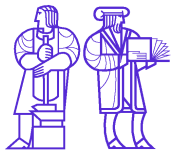


Labels

- Every data item has an attached label
- 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
- May have repeated owners



Assignment

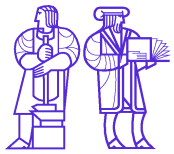
- Assignment relabels a value

```
x = y;
```

- $\underline{y} \sqsubseteq \underline{x}$ means

  For every policy in $\underline{y}$, there is a policy in $\underline{x}$ that is at least as restrictive

- Binary label relation $\sqsubseteq$ defines the legal relabelings

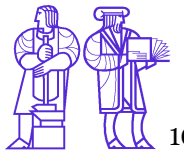


Assignment Example

```
int {Bob: Bob, Preparer}  y;
int {Bob: Bob; Preparer: Preparer}  x;
x = y;
```

$\underline{y} \sqsubseteq \underline{x}$?

{Bob: Bob, Preparer} $\sqsubseteq$ {Bob: Bob; Preparer: Preparer}

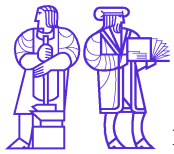


Computation

- Combining values: new label is *join* (⊔) of input labels

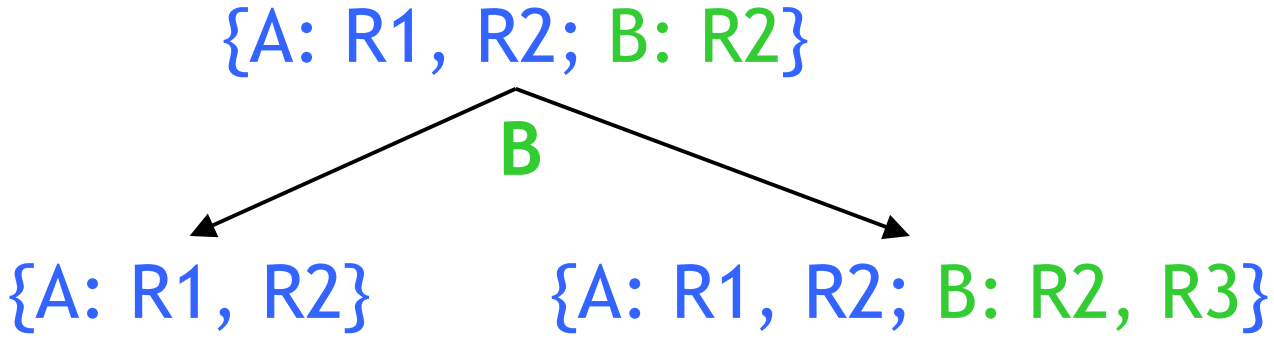
$$y + z \quad \rightarrow \quad \underline{y} \sqcup \underline{z} = \underline{y} \cup \underline{z}$$

- Label on data reflects all its sources

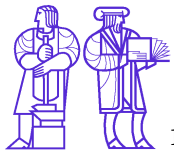


Declassification

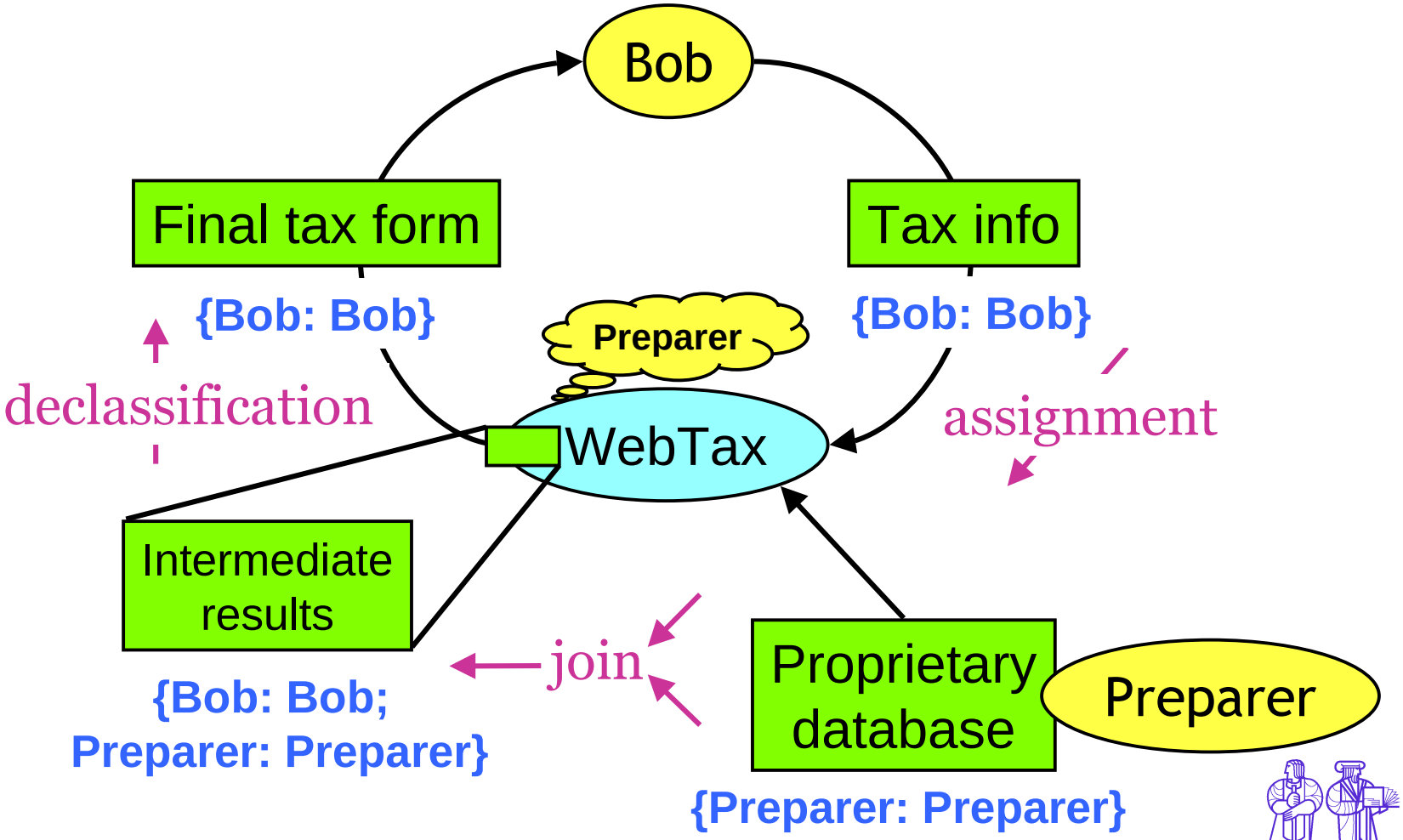
- A principal can rewrite its part of the label



- Other owners' policies still respected



WebTax Example



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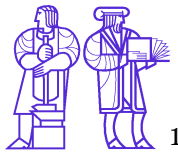
- Static checking & inference
- Soundness & completeness



Checking Annotated Programs

- Annotate Java with labels
- Variables have type + label
- Label checking = type checking
- Handles implicit flows, exceptions, objects, dynamic type tests, etc.
- Label polymorphism, inference
- Implemented: **JFlow** compiler

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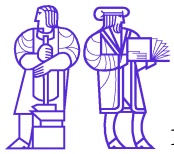
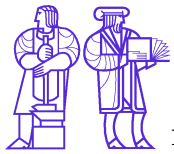


Sound Relabeling Rule

- Safe incremental relabelings:
  - remove a reader: {A:B,C} ➔ {A:B}
  - add a policy: {A:B} ➔ {A:B; C:D}
  - replace an owner by a superior: {A:B} ➔ {A’:B}
  - add a superior reader: {B:A} ➔ {B:A,A’}
- Every sequence of relabelings is safe
- What does “safe” mean?



Label Semantics

- Label L denotes a set of *flows* $\mathbf{X}(L)$
- Flow is a (*owner*, *reader*) pair
- Omitted owners allow all flows:

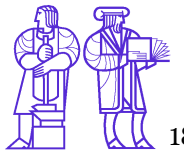
$$\mathbf{X}(\{ A: B ; C: A \}) =$$

$$\{ (A, B), (C, A), (B, A), (B, B), (B, C) \}$$

- Constraints from principal hierarchy:

$$r' \succcurlyeq r \;\&\; (o, r) \in \mathbf{X}(L) \rightarrow (o, r') \in \mathbf{X}(L)$$

$$o' \succcurlyeq o \;\&\; (o', r) \notin \mathbf{X}(L) \rightarrow (o, r) \notin \mathbf{X}(L)$$



Safety

- A relabeling is safe if it does not create new flows:

$$L_1 \rightarrow L_2 \text{ is safe if } \mathbf{X}(L_1) \supseteq \mathbf{X}(L_2)$$

- Problem: $\mathbf{X}(L_1)$, $\mathbf{X}(L_2)$ evaluated statically using partial knowledge of principal hierarchy; safety condition must hold in run-time hierarchy!

Soundness/Completeness

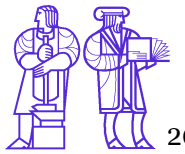
- **Soundness: (⇒)**

  For every principal hierarchy consistent with a set of static observations, a relabeling does not create new flows

- **Completeness: (⇐)**

  The relabeling rule is the most permissive sound rule (& captures incremental rules)

$$P \vdash L_1 \sqsubseteq L_2 \Leftrightarrow \forall_{P' \supseteq P} \mathbf{X}(P', L_1) \supseteq \mathbf{X}(P', L_2)$$



Inference & Lattice Properties

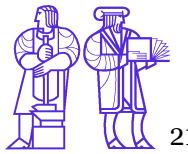
- Derived values: at least as restrictive as the input values (least upper bound)

  $x = y + z$ $\qquad\qquad$ $\underline{y} \sqcup \underline{z} \sqsubseteq \underline{x}$

- Inferred variables: at most as restrictive as uses (greater lower bound)

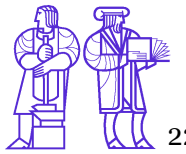
  $y = x;\ z = x;$ $\qquad\qquad$ $\underline{x} \sqsubseteq \underline{y} \sqcap \underline{z}$

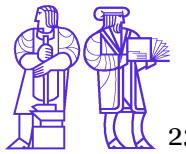
- Label model ($\sqsubseteq$) provides both LUB and GLB needed for inference



Related Work

- Bell, LaPadula, 1975
- Denning, 1976
- Denning & Denning, 1977
- McCollum, et al. IEEE S & P, 1990
- Ferrari, et al. IEEE S & P, 1997



Conclusions

- New decentralized label model
  - safe declassification
  - supports groups, roles
- Supports static checking
  - distributive LUB/GLB operators
  - label inference algorithm
- Formal semantics
  - relabeling proven sound and complete