Types for Information Flow

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Based on the paper by Myers, A. C. “JFlow: practical mostly-static information flow control”. In POPL '99

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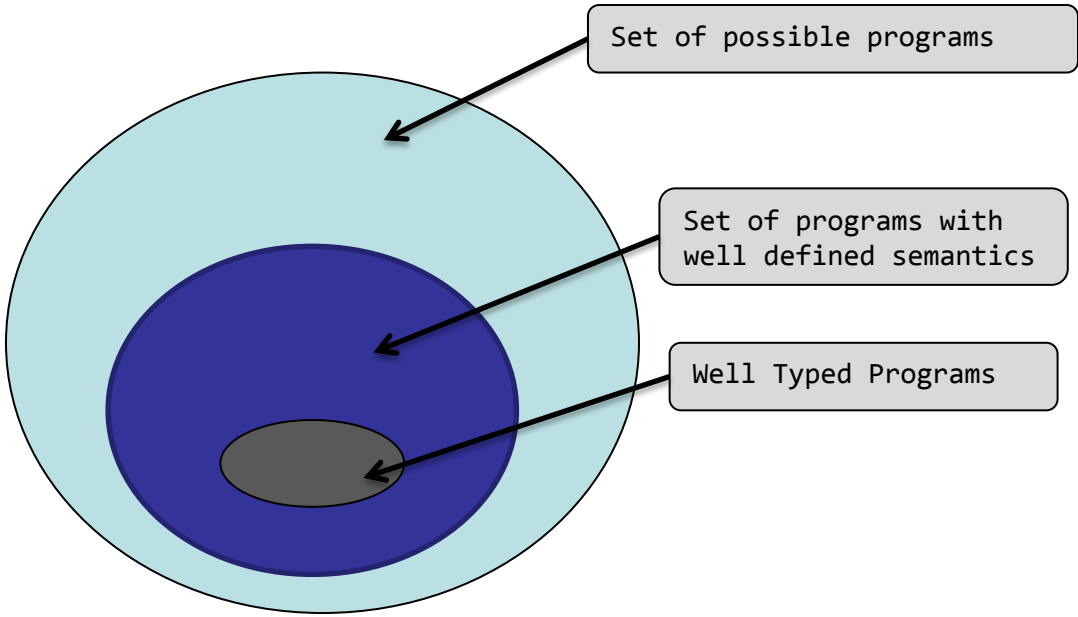
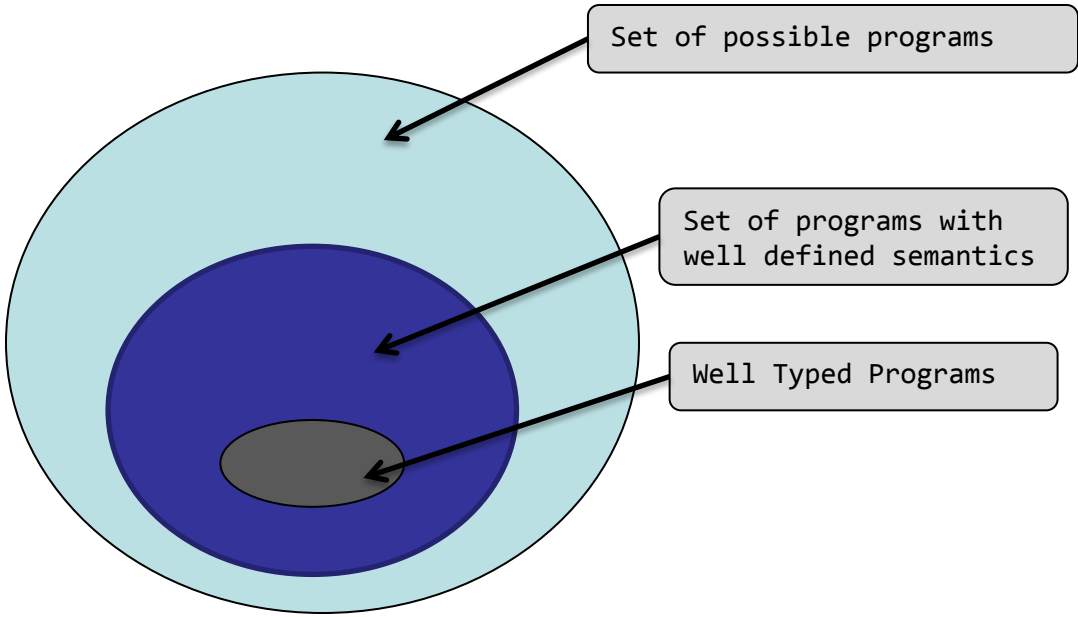
Recap



Functional World:

- evaluation proceeds through reduction rules
- types impose constraints on the shape of the program
- a program with a legal shape (according to the type system)
  - always has an available reduction rule (unless it has terminated)
  - the reduction rule will produce a new program with a legal shape

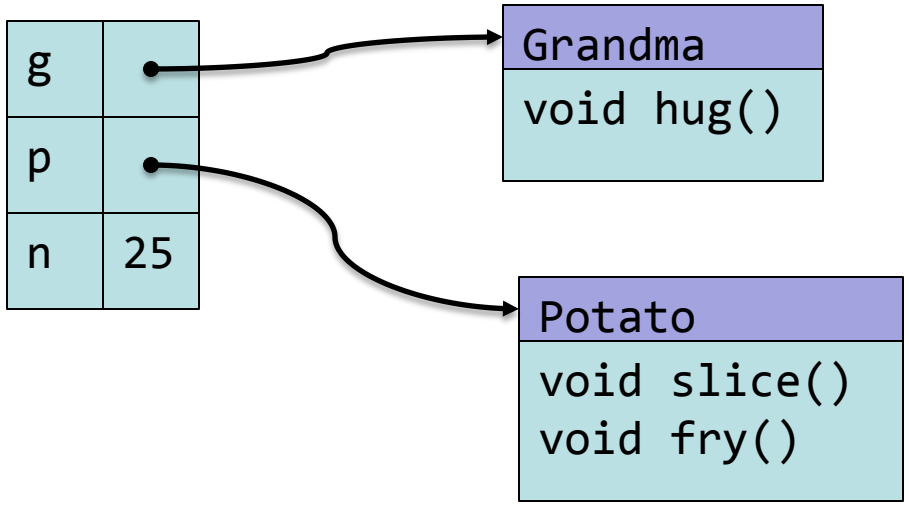
Recap



Imperative World:

- evaluation involves updating a store
- types place restrictions on the program store
  - this allows static reasoning about legal operations on the objects in the store

Recap



~~p.hug()~~

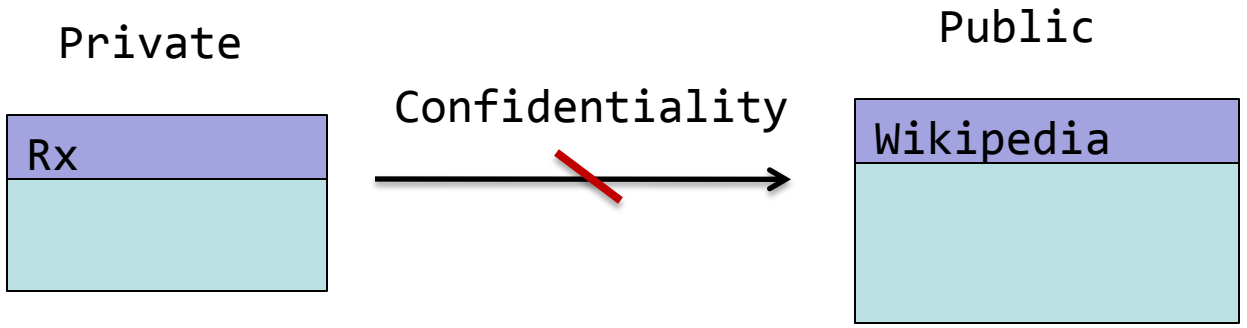
~~g.fry()~~

~~n.hug()~~

Imperative World:

- evaluation involves updating a store
- types place restrictions on the program store
  - this allows static reasoning about legal operations on the objects in the store

Enforcing Security Properties

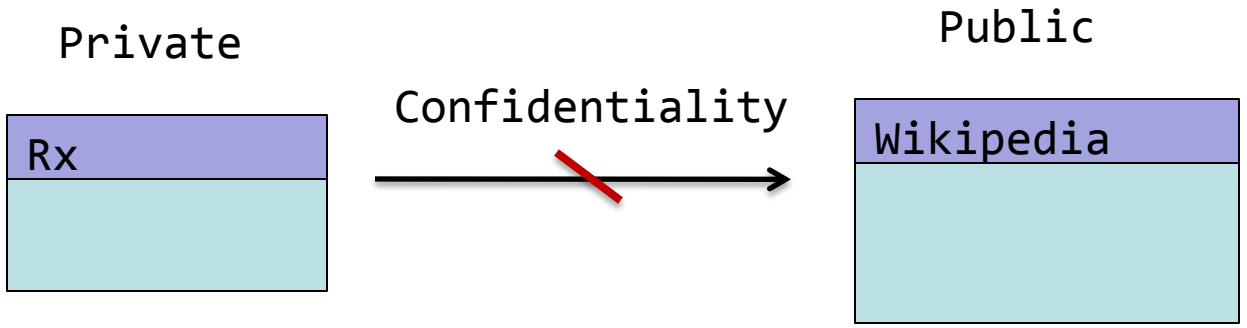



```
Rx myrx = getMyRx();
Wikipedia w = getWPEntry("Armando");

w.addEntry(myrx.toString());
```

```
w.write("YES");
```

Enforcing Security Properties



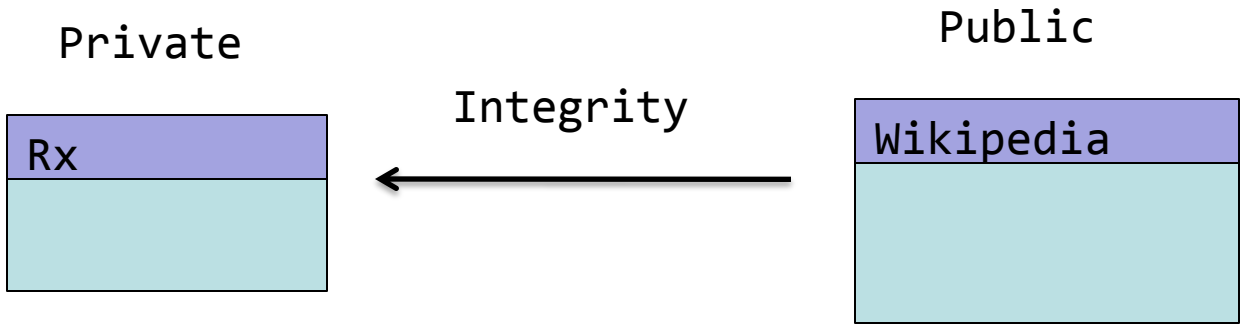

```
Rx myrx = getMyRx();
Wikipedia w = getWPEntry("Armando");

w.write("Hemorrhoids :");
p.val = myrx.contains("Preparation H");
if(q.val){
        w.write("YES");
}
```

If p==q information clearly leaks

Even if p!=q, information can still leak if p!=q was caused by some information about myrx.

Enforcing Security Properties

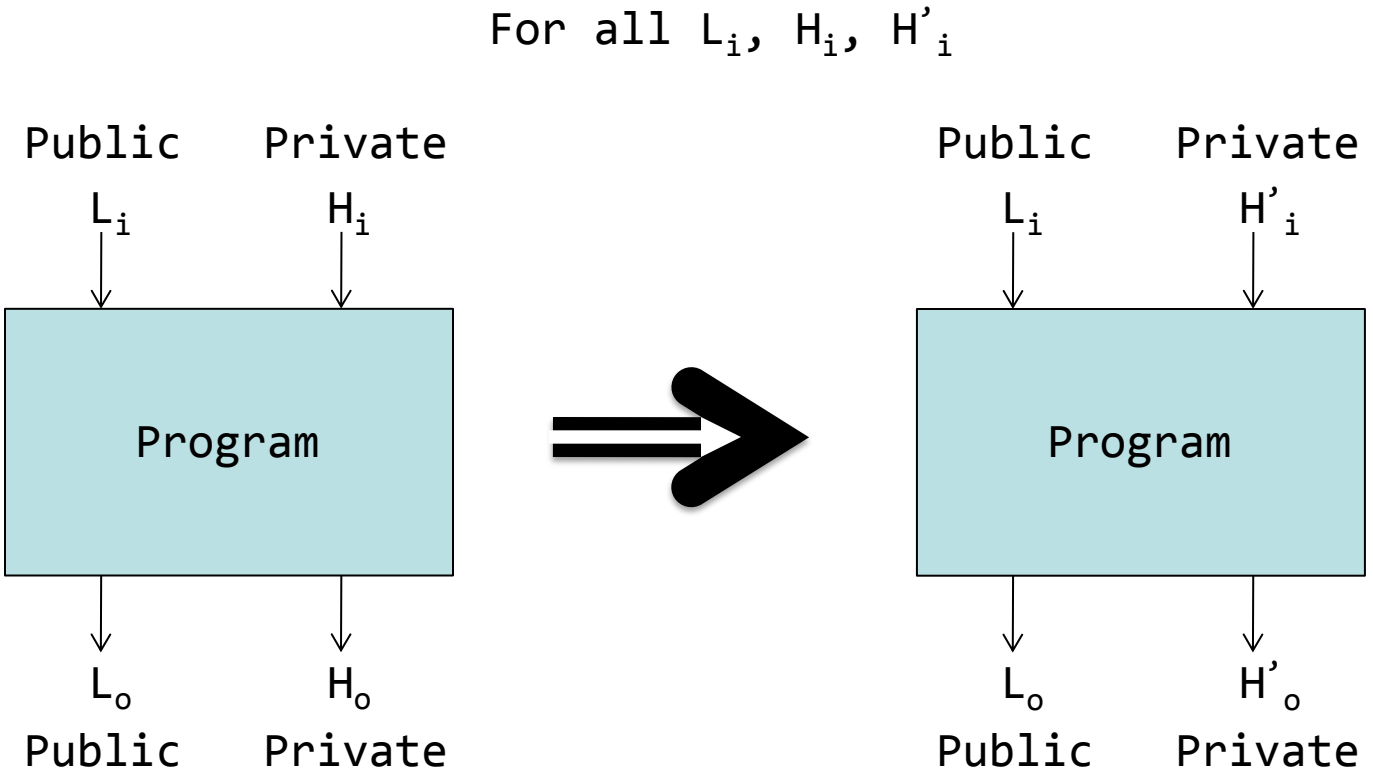



```
class Doctor{
        Rx cureFlu(){
                Rx myrx = new Rx();
                Wikipedia w = getWPEntry(“Flu”);
                myrx.set(w.getSubEntry(“Treatment”));
                return myrx;
        }
}
```

What is information flow?

If there is no information flow from private to public, then a change in a private input can not affect a public output

- you can't determine this from a single execution



Solution Strategy

We proceed through the following two steps

- Define a dynamic labeling scheme so that at any given time, the labels in a piece of data tell us whether it's OK to leak it or not.
  - Labels turn a global property about all executions into a local property in a conservative way
  - This will be the dynamic semantics against which we can prove type safety.
- Define a type system that allows us to approximate the set of labels that the data pointed at by a variable can have.
  - If an action is ok according to the conservative approximation, we know it would be ok according to the dynamic scheme.

Labeling Data With Security Policies

Policies for information flow

```
Owner: reader1, reader2, reader3
```

- "according to owner, this data can only be read by reader1, reader2, or reader3"

Label `{ policy1, policy2, policy3 }`

- If an owner is not mentioned, it is assumed she has no privacy concerns

Why do we need an owner?

Revocation

Principals

Owners and readers are principals

- user, group or role

act_for relationship

- allows principals to act for other principals

```
Armando act_for Faculty
```

Labels form a lattice

```
L1 <= L2
```

L1 can be relabeled to L2

- means that L2 is more restrictive (fewer readers)
- Warning: this is counterintuitive
  - L2 actually has fewer readers.

Partial Order defines a lattice

- Least upper bound ⊔
- Least fixed point
- bottom

If a variable is certified to handle data with L2 labels correctly, we can trust that variable to hold a value with label L1

- Just like subtyping!

Labels form a lattice

Question

{Joe: Ann, Jill} <= {Joe:Ann}

{Joe: (Ann, Jill), Tim:Ann} <= {Joe:(Ann), Tim:Ann}

{Joe: (Ann), Tim:Ann} ??? {Joe:(Ann)}

Assignment

```
x{L2} := v{L1};
```

```
L1 <= L2
```

Can only assign to a variable to a more restrictive label

Binary Operations

```
a{L1} + b{L2};
```

Trick question:

- What should be the label for a+b?

```
int{Joe:everyone} a, b, c;
...
int{Joe:Joe} p;
c = 0;
if(p){
    c = a + b;
}
```

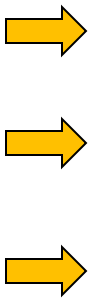
- What information would be leaked if this code were to execute?

Information flow through control

Information flow through the PC

- We need to keep track of the information that is leaked just from knowing that the computation reached a particular point.

```
int{Joe:everyone} a, b, c;
...
int{Joe:Joe} p;
c = 0;
if(p){
    c = a + b;
}
```



PC Label
{}
{Joe:Joe}

Simple scheme except for non-structured control

- return, continue, throw, break

Formalizing the type system

Basic judgments

$$A \vdash E : X$$

Type Environment

Expression

Set of relevant labels.

X is a map with several values

- X[nv] = label of the expression if it terminates normally
- X[n] = label that would be leaked if execution terminated after evaluating this expression
- …

Rules

$$\frac{true}{A \vdash literal : X_{\emptyset}[\underline{\mathsf{n}} := A[\underline{\mathsf{pc}}], \underline{\mathsf{nv}} := A[\underline{\mathsf{pc}}]]}$$

If evaluating a literal somehow caused the program to terminate, I would leak the pc label.

The value of the literal also carries information about the PC label.

```
if(p){
   x = literal
}
```

This is what prevents the code above from leaking information; the assignment only type checks if x is compatible with the PC label

Rules

$$\frac{A[v] = \langle \mathsf{var}\ \left[\mathsf{final}\right]\ T\{L\}\ uid\rangle \qquad X = X_{\emptyset}[\underline{\mathsf{n}} := A[\underline{\mathsf{pc}}], \underline{\mathsf{nv}} := L \sqcup A[\underline{\mathsf{pc}}]]}{A \vdash v : X}$$

Least upper bound. The return value must carry the labels of both the variable and the pc.

Rules

$$\frac{A \vdash E : X \qquad A[v] = \langle \mathsf{var}\ T\{L\}\ uid \rangle \qquad A \vdash X[\underline{\mathsf{nv}}] \sqsubseteq L}{A \vdash v = E : X}$$

This is the label of expression E.
It has to be less restrictive than L

Rules

$$\frac{A \vdash E : X_E \qquad A[\underline{\mathsf{pc}} := X_E[\underline{\mathsf{nv}}]] \vdash S_1 : X_1 \qquad A[\underline{\mathsf{pc}} := X_E[\underline{\mathsf{nv}}]] \vdash S_2 : X_2 \qquad X = X_E[\underline{\mathsf{n}} := \underline{\emptyset}] \oplus X_1 \oplus X_2}{A \vdash \mathsf{if}\ (E)\ S_1\ \mathsf{else}\ S_2 : X}$$

This computes the join of XE, X1, X2, except we don't care about XE[n] so we set it to {}.

Rules

extend the environment to add any new variable declarations

update PC in the new environment

$$\frac{A \vdash S_1 : X_1 \qquad extend(A, S_1)[\underline{\mathsf{pc}} := X_1[\underline{\mathsf{n}}]] \vdash S_2 : X_2 \qquad X = X_1[\underline{\mathsf{n}} := \underline{\emptyset}] \oplus X_2}{A \vdash S_1; S_2 : X}$$

Example

x {Joe: Erika} = {Joe: Erika, Peter}

if(x){

  p{Tim:Erika, Joe:Erika} = {Tim: Everyone}

}

6.820 Fundamentals of Program Analysis
Fall 2015