Software Security

Information Flow

(Chapter 5 of lecture notes on language-based security)

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Motivating example

Imagine using a mobile phone app to

1. **locate nearest hotel using google**
2. **book a room with your credit card**

Sensitive information?

- **location information & credit card no**

(Un)wanted information flows?

- **location should be leaked to google *only***
- **credit card info should be leaked to hotel *only***

Such information flow policies are an interesting class of security policies

Motivating example

Suppose that for our mobile phone app we want to enforce

- location should be leaked to google *only*
- credit card info should be leaked to hotel *only*

- *Can OS access control on the app prevent these flows?*

  NO! Access control can give or deny an app access to some information or service, but cannot restrict what the app does with it.

- *More generally, could we enforce this at runtime by monitoring the inputs & outputs of the application?*

  NO! Unless track the information *inside the app with dynamic taint tracking.*

  - Recall PREfast supported static taint tracking – clumsily – also inside the code

Information Flow

- An interesting category of security requirements is about information flow.

  Eg
  - no confidential information should leak over network
  - no untrusted input from network should leak into database
- Information flow properties can be about confidentiality or integrity
- Note the difference with access control:
  - access control is about *access only*

    (eg for mobile phone app, access to the location data)
  - information flow is *also* about *what you do with data after you accessed it*

    (eg how you process & forward location data)

- **Warning: possible exam questions coming up!**

Example Information Flow - Confidentiality

```
String hi; // security label secret
String lo; // security label public
```

Which program fragments (may) cause problems if `hi` has to be kept confidential?

```
1. hi = lo;
2. lo = hi;
3. lo = "1234";
4. hi = "1234";
```

```
5. println(lo);
6. println(hi);
7. readln(lo);
8. readln(hi);
```

Example Information Flow - Confidentiality

```
String hi; // security label secret
String lo; // security label public
```

Which program fragments (may) cause problems if `hi` has to be kept confidential?

✓ `1. hi = lo;`
✗ `2. lo = hi;`
✓ `3. lo = "1234";`
? `4. hi = "1234";`

✓ `5. println(lo)`
✗ `6. println(hi);`
✓ `7. readln(lo);`
? `8. readln(hi);`

Example Information Flow - Confidentiality

```
String hi; // security label secret
String lo; // security label public
```

Which program fragments (may) cause problems if `hi` has to be kept confidential?

```
1. lo = some_function_call(hi);
2. lo = encrypt(hi,AESkey);
```

Example Information Flow - *Integrity*

```
String hi; // high integrity (trusted) data
String lo; // low integrity (untrusted) data
```

Which program fragments (may) cause problems if integrity of hi is important ?

```
1. hi = lo;
2. lo = hi;
3. lo = "1234";
4. hi = "1234";
```

```
5. println(lo);
6. println(hi);
7. readln(lo);
8. readln(hi);
```

Example Information Flow - *Integrity*

```
String hi; // high integrity (trusted) data
String lo; // low integrity (untrusted) data
```

Which program fragments (may) cause problems if integrity of hi is important ?

✗ `1. hi = lo;`
✓ `2. lo = hi;`
✓ `3. lo = "1234";`
✓ `4. hi = "1234";`
✓ `5. println(lo);`
✓ `6. println(hi);`
✓ `7. readln(lo);`
✗ `8. readln(hi);`

Example Information Flow - *Integrity*

```
String hi; // high integrity (trusted) data
String lo; // low integrity (untrusted) data
```

Which program fragments (may) cause problems if integrity of hi is important ?

```
1. hi = some_function_call(lo);
2. hi = convertToUpperCase(lo);
3. hi = HTMLencode(lo);
4. hi = checkAndStripMAC(lo);
   // where MAC is MessageAuthenticationCode
```

Duality between integrity & confidentiality

Integrity and confidentiality are *duals :*

if you "flip" everything in a property or example for confidentiality,

you get a corresponding property or example for integrity

For example

inputs are dangerous for integrity,
outputs are dangerous for confidentiality

Information flow

- Information flow properties are about ruling out unwanted influences/dependencies/interference/observations

- Note the difference between data flow properties and visibility modifiers (eg public, private) or, more generally, access control
  - it's not (just) about accessing data, but also about what you do with it

Questions

- What do we mean by information flow? (informally)
- How can we specify information flow policies?
- How can we enforce or check them?
  - dynamically (runtime)
  - statically (compile time) – by type systems
- What is the semantics (ie. meaning) of information flow formally?

Trickier examples for confidentiality

```
int hi; // security label secret
int lo; // security label public
```

Which program fragments (may) cause problems for confidentiality?

```
1. if (hi > 0) { lo = 99; }
2. if (lo > 0) { hi = 66; }
3. if (hi > 0) { print(lo);}
4. if (lo > 0) { print(hi);}
```

Trickier examples for confidentiality

```
int hi; // security label secret
int lo; // security label public
```

Which program fragments (may) cause problems for confidentiality?

✗ `1. if (hi > 0) { lo = 99; }`
✓ `2. if (lo > 0) { hi = 66; }`
✗ `3. if (hi > 0) { print(lo);}`
✗ `4. if (lo > 0) { print(hi);}`

implicit
aka
indirect flows

indirect vs direct flows

There are (at least) two kinds of information flows

- direct aka explicit flows

  by "direct" assignment or leak

  eg `lo=hi;` or `println(hi);`
- indirect aka implicit flows

  by indirect "influence"

  eg `if (hi > 0} { lo = 99; }`

Implicit flows can be partial, ie leak *some* but not *all* info

Eg the example above only leaks the sign of `hi`, not its value.

Trickier examples for confidentiality

Example

```
int hi; // security label secret
int lo; // security label public
```

Which program fragments (may) cause problems for confidentiality?

```
1. while (hi>99) do {....};
2. while (lo>99) do {....};
3. a[hi] = 23; // where a is high/secret
4. a[hi] = 23; // where a is low/public
5. a[lo] = 23; // where a is high/secret
6. a[lo] = 23; // where a is low/public
```

Trickier examples for confidentiality

```
int hi; // security label secret
int lo; // security label public
```

✗ 1. `while (hi>99) do {....};`
`// timing or termination may reveal if hi > 99`

✓ 2. `while (lo>99) do {....};` // no problem

✗ 3. `a[hi] = 23; // where a is high/secret`
`// exception may reveal if hi is negative`

✗ 4. `a[hi] = 23; // where a is low/public`
`// contents of a may reveal value of hi and, again,`
`// exception may reveal if hi is negative`

✗ 5. `a[lo] = 23; // where a is high/secret`
`// exception may reveal the length of a, which may be secret`

✓ 6. `a[lo] = 23; // where a is low/public` - no problem

Hidden channels

More subtle forms of indirect information flows can arise via hidden channel aka covert channels aka side channels

- (non)termination

  eg `while (hi>99) do {....};`

  or `if (hi=99) then {"loop"} else {"terminate"}`

- execution time

  eg `for (i=0; i<hi; i++) {...};`

  or `if (hi=1234) then {...} else {...}`

- exceptions

  eg `a[i] = 23` may reveal length of a (if i is known),

  or leak info about `i` (if length of a is known),

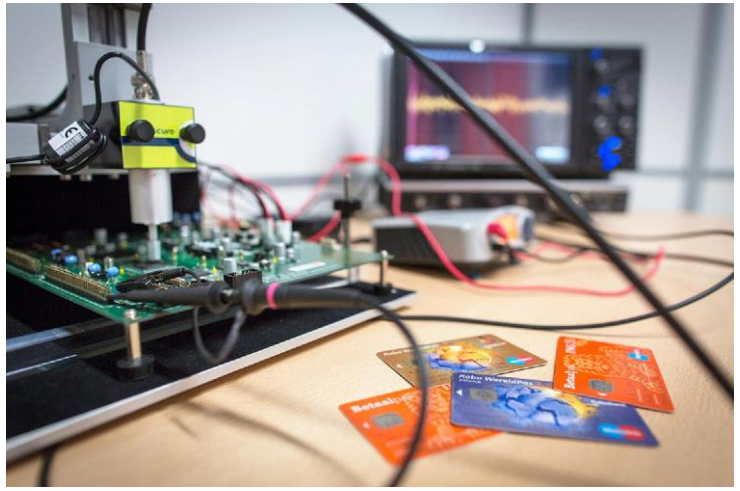
  or reveal if a is null..

Hidden channels

- Apart from timing & terminations, there are many more side-channels:
  - noise
  - power consumption
  - EM radiation – aka TEMPEST attacks

- In the courses Physical Attacks on Secure Systems and Cryptographic Engineering you can find out more about hidden channels

- In our lab we have set-ups for power analysis & EM radiation



How can we *statically* enforce information flow policies by means of a type system?

Type-based information flow

Type systems have been proposed as way to restrict information flow.

- most of the theoretical work considers confidentiality, but the same works for integrity

Practical problem: often very (too) restrictive, because of difficulty in ruling out implicit flows

Types for information flow (confidentiality)

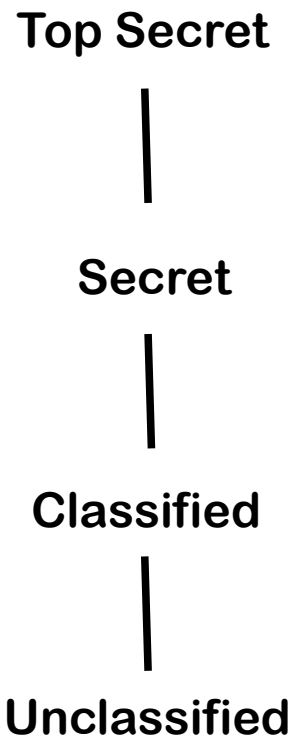
- We consider a lattice (in Dutch: tralie) of different security levels

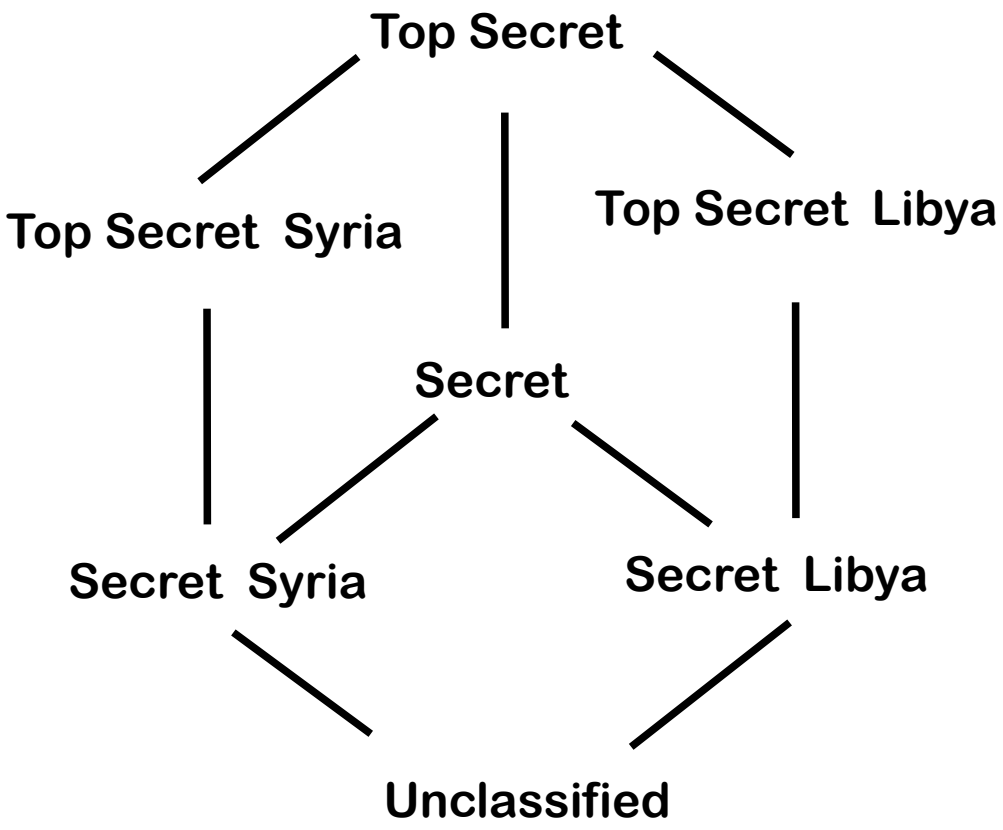
- For simplicity, just two levels
  - H(igh) or confidential, secret
  - L(ow) or public

- Typing judgements e:t
  meaning e has type t

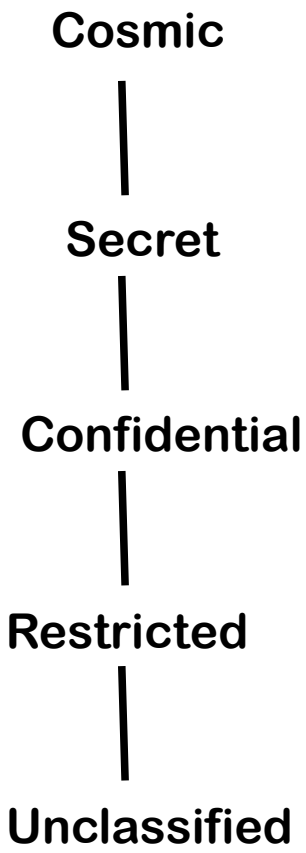
- implicitly with respect to a context $x_1:t_1$, ... $x_n:t_n$ that gives levels of program variables

More complex lattices





NATO classification



Rules for expressions

e : t means e contains information of level t or *lower*

- **variable** x:t if x is a variable of type t
- **operations** $\dfrac{e:t \quad e':t}{e+e' : t}$ for some binary operation + (similar for n-ary)
- **subtyping** $\dfrac{e:t \quad t \leq t'}{e:t'}$

Rules for commands

s : ok t means s only writes to level t or *higher*

- assignment
$$\frac{e : t \qquad x \text{ is a variable of type } t}{x{:=}e \ : \text{ok } t}$$

- if-then-else
$$\frac{e : t \qquad c1 : \text{ok } t \qquad c2 : \text{ok } t}{\text{if } e \text{ then } c1 \text{ else } c2 : \text{ok } t}$$

- subtyping
$$\frac{c : \text{ok } t \qquad t \geq t'}{c : \text{ok } t'}$$

ie. ok t $\leq$ ok t' iff t $\geq$ t' (anti-monotonicity)

Rules for commands

s : ok t means s only writes to level t or *higher*

- composition

$$\frac{c1 : ok\ t \qquad c2 : ok\ t}{c1;c2 : ok\ t}$$

- while

$$\frac{e : t \qquad c : ok\ t}{\text{while } e \text{ do } c : ok\ t}$$

Beware

Beware of the confusing difference in directions

e : t means **e contains information of level t or *lower***

s : ok t means **s only writes to level t or *higher***

For people familiar will Bell – LaPadula access control :
there you have the same confusion,
in the “no read up” & “no write down” rules