Access Control and Privacy Policies (7)

Email: christian.urban at kcl.ac.uk
Office: S1.27 (1st floor Strand Building)

Slides: KEATS (also homework is there)

Judgements

$$\Gamma \vdash F$$

Judgements

entails sign

$$\Gamma \vdash F$$

a single formula

Gamma
stands for a collection of formulas
("assumptions")

Judgements

entails sign

$$\Gamma \vdash F$$

a single formula

Gamma
stands for a collection of formulas
("assumptions")

Gimel (Phoenician), Gamma (Greek), C and G (Latin), Gim (Arabic),
?? (Indian), Ge (Cyrillic)

Inference Rules

premisses

$$\frac{\Gamma \vdash F_1 \qquad \Gamma \vdash F_2}{\Gamma \vdash F_1 \wedge F_2}$$

conclusion

Inference Rules

premisses

$$\frac{\Gamma \vdash F_1 \quad \Gamma \vdash F_2}{\Gamma \vdash F_1 \wedge F_2}$$

conclusion

P says $F \vdash Q$ says $F \wedge P$ says G

Inference Rules

premisses

$$\frac{\Gamma \vdash F_1 \quad \Gamma \vdash F_2}{\Gamma \vdash F_1 \wedge F_2}$$

conclusion

$$\underbrace{P\ \mathsf{says}\ F}_{\Gamma} \vdash \underbrace{Q\ \mathsf{says}\ F}_{F_1} \wedge \underbrace{P\ \mathsf{says}\ G}_{F_2}$$

$$\frac{\Gamma \vdash F_1 \Rightarrow F_2 \quad \Gamma \vdash F_1}{\Gamma \vdash F_2}$$

$$\frac{\Gamma \vdash F}{\Gamma \vdash P \text{ says } F}$$

We want to prove

$$\Gamma \vdash \text{del\_file}$$

We want to prove

$$\Gamma \vdash \text{del\_file}$$

There is an inference rule

$$\frac{\Gamma \vdash F}{\Gamma \vdash P \text{ says } F}$$

We want to prove

$$\Gamma \vdash \text{del\_file}$$

There is an inference rule

$$\frac{\Gamma \vdash F}{\Gamma \vdash P \text{ says } F}$$

So we can derive $\Gamma \vdash$ Alice says del_file.

We want to prove

$$\Gamma \vdash \text{del\_file}$$

There is an inference rule

$$\frac{\Gamma \vdash F}{\Gamma \vdash P \text{ says } F}$$

So we can derive $\Gamma \vdash$ Alice says del_file.

Γ contains already Alice says del_file.
So we can use the rule

$$\overline{\Gamma, F \vdash F}$$

Done. Qed.

We want to prove

$$\Gamma \vdash \text{del\_file}$$

There is an inference rule

$$\frac{\Gamma \vdash F}{\Gamma \vdash P \text{ says } F}$$

So we can derive $\Gamma \vdash$ Alice says del_file.

Γ contains already Alice says del_file.
So we can use the rule

$$\overline{\Gamma, F \vdash F}$$

What is wrong with this? **Done. Qed.**

Digression: Proofs in CS

Formal proofs in CS sound like science fiction?
Completely irrelevant! Lecturers gone mad!

Digression: Proofs in CS

Formal proofs in CS sound like science fiction?
Completely irrelevant! Lecturers gone mad!

- in 2008, verification of a small C-compiler
  - "if my input program has a certain behaviour, then the compiled machine code has the same behaviour"
  - is as good as `gcc -O1`, but less buggy
- in 2010, verification of a micro-kernel operating system (approximately 8700 loc)
  - 200k loc of proof
  - 25 - 30 person years
  - found 160 bugs in the C code (144 by the proof)

Bob Harper
(CMU)

Frank Pfenning
(CMU)

published a proof about a specification in a journal (2005), $\sim$31pages

Bob Harper
(CMU)

Frank Pfenning
(CMU)

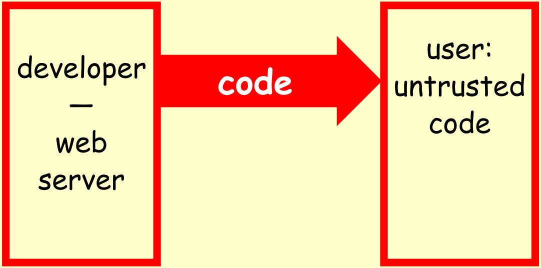
published a proof about a specification in a journal (2005), ∼31pages

Andrew Appel
(Princeton)

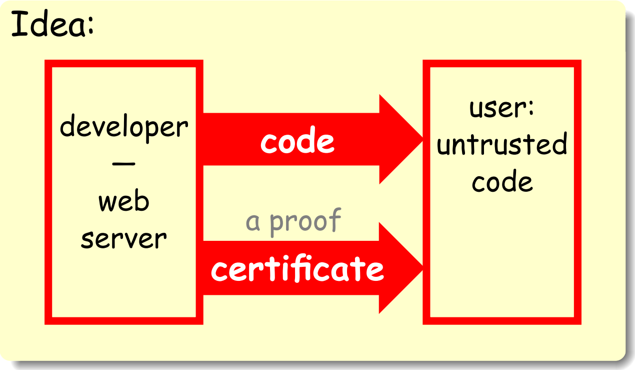
relied on their proof in a **security** critical application

Proof-Carrying Code

Idea:

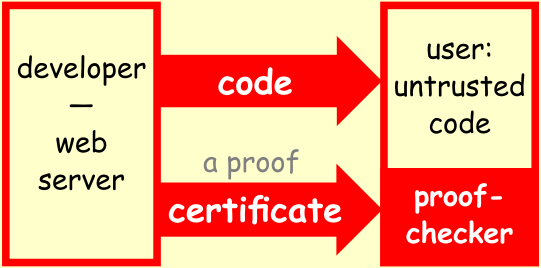


Proof-Carrying Code



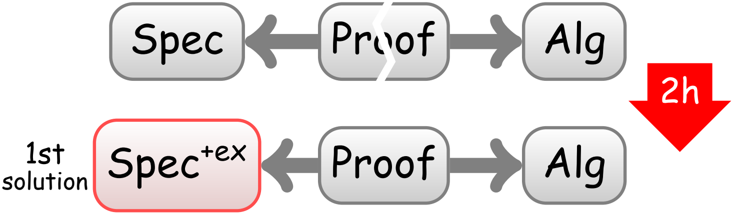
Proof-Carrying Code

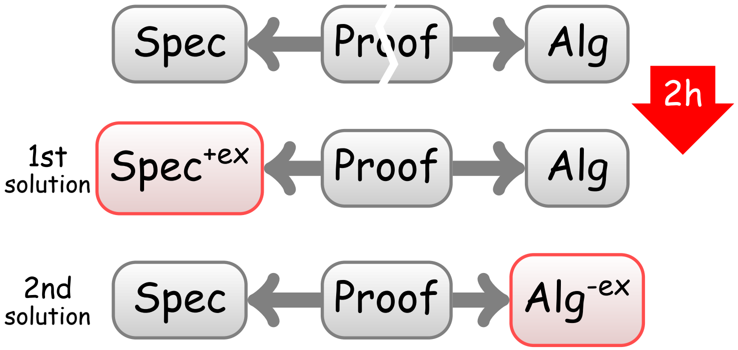
Idea:

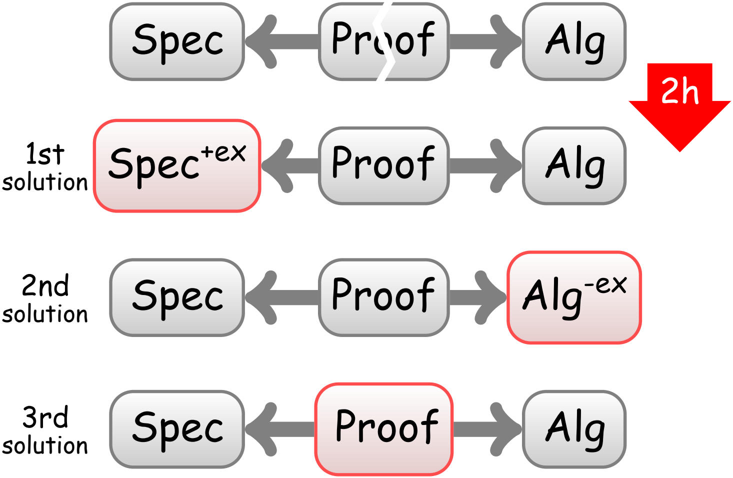



Spec
Proof
Alg

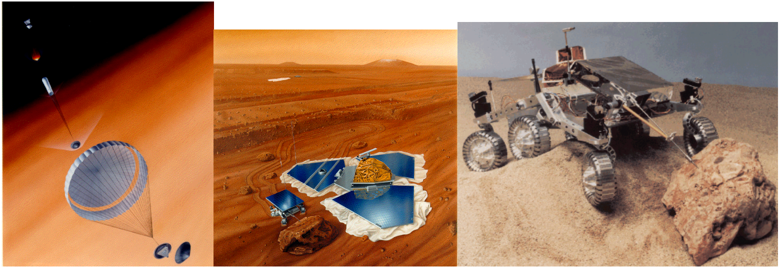

Spec
Proof
Alg


Spec
Proof
Alg
2h
1st solution
Spec+ex
Proof
Alg


Spec
Proof
Alg
2h
1st solution
Spec+ex
Proof
Alg
2nd solution
Spec
Proof
Alg-ex


Spec
Proof
Alg
2h
1st solution
Spec+ex
Proof
Alg
2nd solution
Spec
Proof
Alg-ex
3rd solution
Spec
Proof
Alg

Mars Pathfinder Mission 1997



- despite NASA's famous testing procedure, the lander crashed frequently on Mars
- problem was an algorithm not used in the OS

Priority Inheritance Protocol

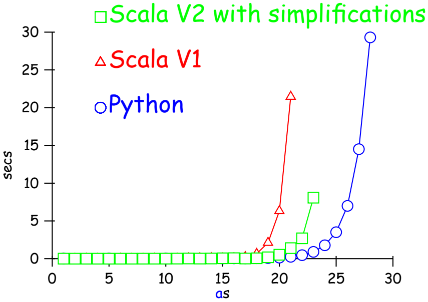
- ...a scheduling algorithm that is widely used in real-time operating systems
- has been "proved" correct by hand in a paper in 1983
- ...but the first algorithm turned out to be incorrect, despite its "proof"

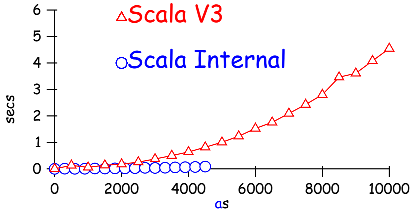
Priority Inheritance Protocol

- ...a scheduling algorithm that is widely used in real-time operating systems
- has been "proved" correct by hand in a paper in 1983
- ...but the first algorithm turned out to be incorrect, despite its "proof"

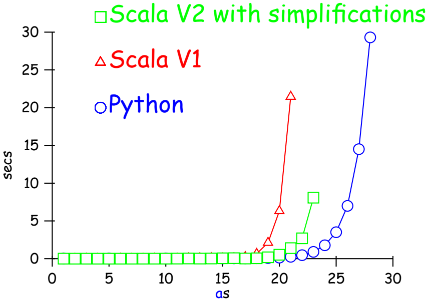
- we specified the algorithm and then proved that the specification makes "sense"
- we implemented our specification in C on top of PINTOS (used for teaching at Stanford)
- our implementation was much more efficient than their reference implementation

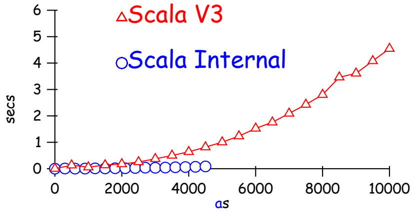
Regular Expression Matching





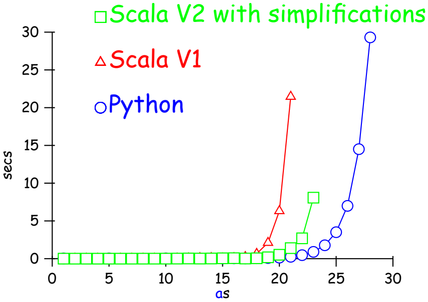
Regular Expression Matching

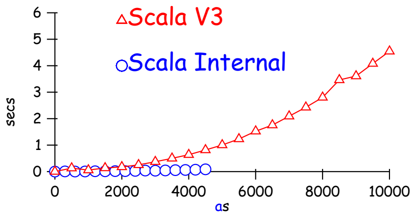




- I needed a proof in order to make sure my program is correct

Regular Expression Matching





- I needed a proof in order to make sure my program is correct

End Digression.
(Our small proof is 0.0005% of the OS-proof.)

One More Thing

- I arrived at King's last year
- Maxime Crochemore told me about a string algorithm (suffix sorting) that appeared at a conference in 2007 (ICALP)
- "horribly incomprehensible", no implementation, but claims to be the best $O(n + k)$ algorithm

One More Thing

- I arrived at King's last year
- Maxime Crochemore told me about a string algorithm (suffix sorting) that appeared at a conference in 2007 (ICALP)
- "horribly incomprehensible", no implementation, but claims to be the best $O(n + k)$ algorithm

- Jian Jiang found 1 error and 1 superfluous step in this algorithm
- he received 88% for the project and won the prize for the best 7CCSMPRJ project in the department
- no proof ... yet

Trusted Third Party

Simple protocol for establishing a secure connection via a mutually trusted 3rd party (server):

Message 1 $A \rightarrow S : A, B$
Message 2 $S \rightarrow A : \{K_{AB}\}_{K_{AS}}$ and $\{\{K_{AB}\}_{K_{BS}}\}_{K_{AS}}$
Message 3 $A \rightarrow B : \{K_{AB}\}_{K_{BS}}$
Message 4 $A \rightarrow B : \{m\}_{K_{AB}}$

Encrypted Messages

- Alice sends a message m

  Alice says m

Encrypted Messages

- Alice sends a message m

  Alice says m

- Alice sends an encrypted message m (with key K)

  Alice says $\{m\}_K$

Encrypted Messages

- Alice sends a message m

$$\textsf{Alice says } m$$

- Alice sends an encrypted message m (with key K)

$$\textsf{Alice says } \{m\}_K$$

- Decryption of Alice's message

$$\frac{\Gamma \vdash \textsf{Alice says } \{m\}_K \quad \Gamma \vdash \textsf{Alice says } K}{\Gamma \vdash \textsf{Alice says } m}$$

Encryption

- Encryption of a message

$$\frac{\Gamma \vdash \textit{Alice says } m \quad \Gamma \vdash \textit{Alice says } K}{\Gamma \vdash \textit{Alice says } \{m\}_K}$$

Trusted Third Party

- Alice calls Sam for a key to communicate with Bob
- Sam responds with a key that Alice can read and a key Bob can read (pre-shared)
- Alice sends the message encrypted with the key and the second key it recieved

$$
\begin{array}{lcl}
A \text{ sends } S & : & \mathsf{Connect}(A, B) \\
S \text{ sends } A & : & \{K_{AB}\}_{K_{AS}} \text{ and } \{\{K_{AB}\}_{K_{BS}}\}_{K_{AS}} \\
A \text{ sends } B & : & \{K_{AB}\}_{K_{BS}} \\
A \text{ sends } B & : & \{m\}_{K_{AB}}
\end{array}
$$

Sending Rule

$$\frac{\Gamma \vdash P \text{ says } F \quad \Gamma \vdash P \text{ sends } Q : F}{\Gamma \vdash Q \text{ says } F}$$

Sending Rule

$$\frac{\Gamma \vdash P \text{ says } F \quad \Gamma \vdash P \text{ sends } Q : F}{\Gamma \vdash Q \text{ says } F}$$

$$P \text{ sends } Q : F \overset{\text{def}}{=} \\ (P \text{ says } F) \Rightarrow (Q \text{ says } F)$$

Trusted Third Party

A sends S : Connect(A, B)
S says (Connect$(A, B) \Rightarrow$
$\qquad \{K_{AB}\}_{K_{AS}} \wedge \{\{K_{AB}\}_{K_{BS}}\}_{K_{AS}})$
S sends A : $\{K_{AB}\}_{K_{AS}} \wedge \{\{K_{AB}\}_{K_{BS}}\}_{K_{AS}}$
A sends B : $\{K_{AB}\}_{K_{BS}}$
A sends B : $\{m\}_{K_{AB}}$

Trusted Third Party

A sends S : Connect(A, B)
S says (Connect$(A, B) \Rightarrow$
$\{K_{AB}\}_{K_{AS}} \wedge \{\{K_{AB}\}_{K_{BS}}\}_{K_{AS}})$
S sends A : $\{K_{AB}\}_{K_{AS}} \wedge \{\{K_{AB}\}_{K_{BS}}\}_{K_{AS}}$
A sends B : $\{K_{AB}\}_{K_{BS}}$
A sends B : $\{m\}_{K_{AB}}$

$\Gamma \vdash B$ says m?

Challenge-Response Protocol

- an engine E and a transponder T share a key K
- E sends out a nonce N (random number) to T
- T responds with $\{N\}_K$
- if E receives $\{N\}_K$ from T, it starts engine

Challenge-Response Protocol

$$
\begin{aligned}
& E \text{ says } N && \text{(start)}\\
& E \text{ sends } T : N && \text{(challenge)}\\
& (T \text{ says } N) \Rightarrow (T \text{ sends } E : \{N\}_K \wedge \\
& \qquad\qquad T \text{ sends } E : \mathrm{Id}(T)) && \text{(response)}\\
& T \text{ says } K && \text{(key)}\\
& T \text{ says } \mathrm{Id}(T) && \text{(identity)}\\
& (E \text{ says } \{N\}_K \wedge E \text{ says } \mathrm{Id}(T)) \Rightarrow \\
& \qquad\qquad \text{start\_engine}(T) && \text{(engine)}
\end{aligned}
$$

$\Gamma \vdash \text{start\_engine}(T)$?

Exchange of a Fresh Key

A and B share a ("super-secret") key K_{AB} and want to share another key

- assumption K_{AB} is only known to A and B

- A sends B : $A, \{N_A\}_{K_{AB}}$
- B sends A : $\{N_A + 1, N_B\}_{K_{AB}}$
- A sends B : $\{N_B + 1\}_{K_{AB}}$
- B sends A : $\{K_{AB}^{new}, N_B^{new}\}_{K_{AB}}$

Assume K_{AB}^{new} is compromised by I

Exchange of a Fresh Key

A and B share a ("super-secret") key K_{AB} and want to share another key

- assumption K_{AB} is only known to A and B

- A sends B : $A, \{N_A\}_{K_{AB}}$
- B sends A : $\{N_A + 1, N_B\}_{K_{AB}}$
- A sends B : $\{N_B + 1\}_{K_{AB}}$
- B sends A : $\{K_{AB}^{new}, N_B^{new}\}_{K_{AB}}$
- A sends B : $\{msg\}_{K_{AB}^{new}}$

Assume K_{AB}^{new} is compromised by I

The Attack

An intruder I convinces A to accept the compromised key K_{AB}^{new}

- A sends B : $A, \{N_A\}_{K_{AB}}$
- B sends A : $\{N_A + 1, N_B\}_{K_{AB}}$
- A sends B : $\{N_B + 1\}_{K_{AB}}$
- B sends A : $\{K_{AB}^{new}, N_B^{new}\}_{K_{AB}}$ recorded by I

The Attack

An intruder I convinces A to accept the compromised key K_{AB}^{new}

- A sends B : $A, \{N_A\}_{K_{AB}}$
- B sends A : $\{N_A + 1, N_B\}_{K_{AB}}$
- A sends B : $\{N_B + 1\}_{K_{AB}}$
- B sends A : $\{K_{AB}^{new}, N_B^{new}\}_{K_{AB}}$ recorded by I
- A sends B : $A, \{M_A\}_{K_{AB}}$
- B sends A : $\{M_A + 1, M_B\}_{K_{AB}}$
- A sends B : $\{M_B + 1\}_{K_{AB}}$
- B sends I : $\{K_{AB}^{newer}, N_B^{newer}\}_{K_{AB}}$ intercepted by I
- I sends A : $\{K_{AB}^{new}, N_B^{new}\}_{K_{AB}}$

The Attack

An intruder I convinces A to accept the compromised key K_{AB}^{new}

- A sends B : $A, \{N_A\}_{K_{AB}}$
- B sends A : $\{N_A + 1, N_B\}_{K_{AB}}$
- A sends B : $\{N_B + 1\}_{K_{AB}}$
- B sends A : $\{K_{AB}^{new}, N_B^{new}\}_{K_{AB}}$ recorded by I
- A sends B : $A, \{M_A\}_{K_{AB}}$
- B sends A : $\{M_A + 1, M_B\}_{K_{AB}}$
- A sends B : $\{M_B + 1\}_{K_{AB}}$
- B sends I : $\{K_{AB}^{newer}, N_B^{newer}\}_{K_{AB}}$ intercepted by I
- I sends A : $\{K_{AB}^{new}, N_B^{new}\}_{K_{AB}}$
- A sends B : $\{msg\}_{K_{AB}^{new}}$ I can read it also

Another Challenge-Response

A and B share the key K_{AB} and want to identify each other

- A sends B : A, N_A
- B sends A : $\{N_A, K'_{AB}\}_{K_{AB}}$
- A sends B : $\{N_A\}_{K'_{AB}}$

Another Challenge-Response

A and B share the key K_{AB} and want to identify each other

- A sends B : A, N_A
- B sends A : $\{N_A, K'_{AB}\}_{K_{AB}}$
- A sends B : $\{N_A\}_{K'_{AB}}$