Formal refinement in Z: Mondex electronic purse

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The application

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Mondex electronic purse

Smart Card for electronic commerce

Autonomous: no external control ==>
all security on card

The difficulty

ITSEC : E1 -- E6 (highest)
increasing formality

E6: *formal* SP (abstract), *formal* architecture (concrete), correctness *proofs*

often thought to be impossible!

Summary: the approach

Functional security properties

A correctness proof

Rigorous hand proofs

Abstract and concrete models

Not everything modelled

Security properties

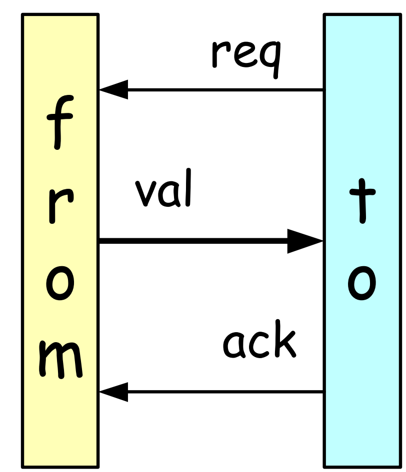
1. "No value created"

$$\Sigma \pounds \geq \Sigma \pounds'$$

2. "All value accounted"
3. "This transfer permitted" (classes, etc)

Formal Z models

- Abstract model
  - promoted world of ‘purses’
  - atomic value transfers
- Concrete model
  - promoted world of ‘purses’
  - n-step value transfer protocol
  - logging protocol
  - ether of protocol messages



Modelled by other means

Eg cryptography: instead, ether

some messages always present $\Rightarrow$ forgeable

some injected only by cards $\Rightarrow$ protected 'somehow' (strength of mechanism arguments)

Correctness proof

Prove that abstract Security Policy is captured by concrete architecture model

Here, SP comprises *functional* properties, which are preserved by *refinement*

Proof style

rigorous hand proof

(not deep: cut, one point, thin, Leibniz, Z toolkit laws, ...)

structure with lemmas

tools: type-checker (fuzz/Formaliser)

human evaluators/reviewers

Summary: proof problems

Resolution of non-determinism

Back to first principles

Deriving 'backwards' rules

Finalisation / i-o refinement

Two refinements required

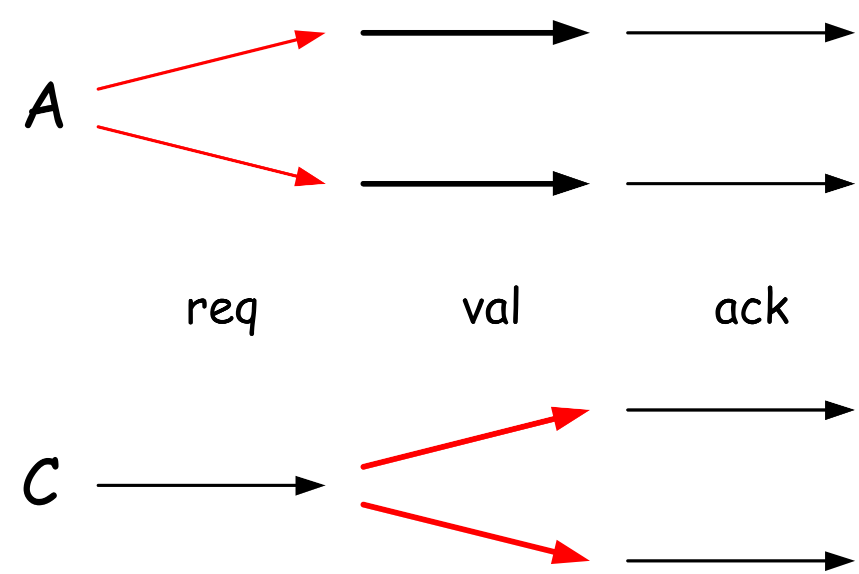
Resolution of non-determinism

Concrete before Abstract (Spivey)

or

Abstract before Concrete (ours)

classic Spivey proof rules not sufficient



Back to first principles

So, what *is* refinement?

consultancy from Jim Woodcock

He, Hoare & Sanders paper

refinement rules $\Rightarrow$ a semantics for Z state-and-operations specifications

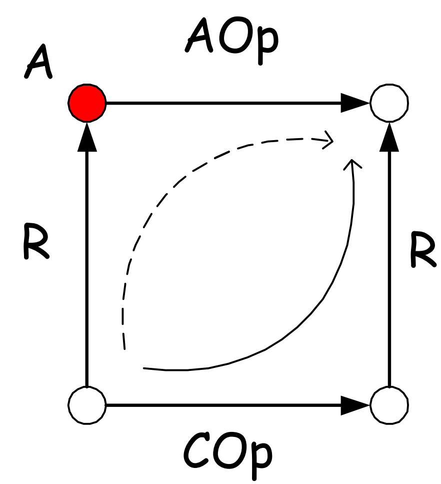
Deriving 'backwards' rules

derived from first principles

now published in
'Woodcock & Davies'

also rederived the
Spivey rules this way

as a sanity check
and confidence booster!



$$COp \; ; \; R'$$

$$\vdash$$

$$\exists A \bullet R \wedge AOp$$

Finalisation

observability

(eg, *Stack* with no *Top* operation)

Not all properties of our model are observed by i/o: so we have a non-trivial finalisation

Input-output refinement

computational model

No good abstraction of ‘balance enquiry’, so:

- abstract: no i/o, + finalisation
- concrete: some i/o, + smaller finalisation

Not sufficient

Forward or backward rules alone not sufficient to prove *all* refinements

We needed a 2-step refinement

1) atomic transfer --> protocol + global constraints

2) global constraints --> unconstrained world

Summary: results

What was proved

Sizes and timescales

Incremental development

FM not the bottleneck

Future developments

What was proved

Proved the design:

- that the security properties hold
- that the protocol implements atomic transfer with error detection
- that local on-card constraints implement the required global constraints

Spec and proof sizes

abstract SP model: ~ 20 pages

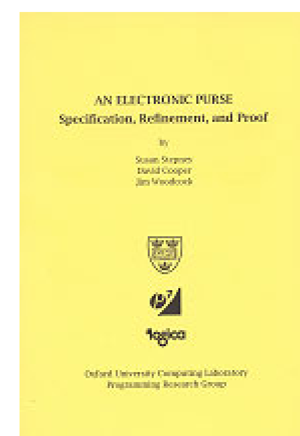
concrete FAD model: ~ 60 pages

hand proof: ~ 200 pages

other derivations: ~ 100 pages

technical monograph PRG-126

Mondex reduced functionality specification, and proof, 230 pages



Incremental development

2 versions: first 'reduced functionality' of Swindon pilot, then upgraded to full 'roll-out functionality'

Main change: multiple currencies

$balance : \mathbb{N}$ became $pocket : CURR \pfun \mathbb{N}$

(*not* $\mathrm{bag}\ CURR$, ie not $pocket : CURR \pfun \mathbb{N}_1$)

Not a bottleneck

Success!

Found an error in the logging protocol

FM work *ahead* of schedule, favourable evaluation report: *so*, requirement for FM is no bar to E6

The future

Was so successful --> now going for E6 approach on other products!

Hand proof enlightening (but tedious): looking at proof tools --- CADiℤ