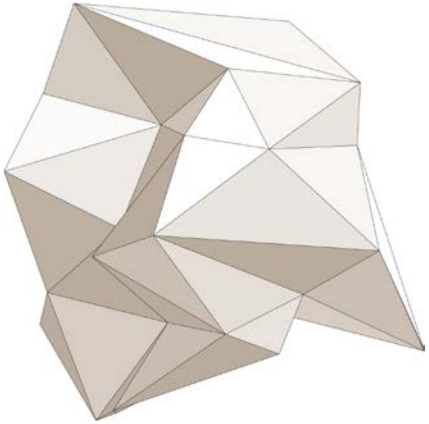


Going Large with Formal Methods on iFACTS

Roderick Chapman, Altran UK

Contents

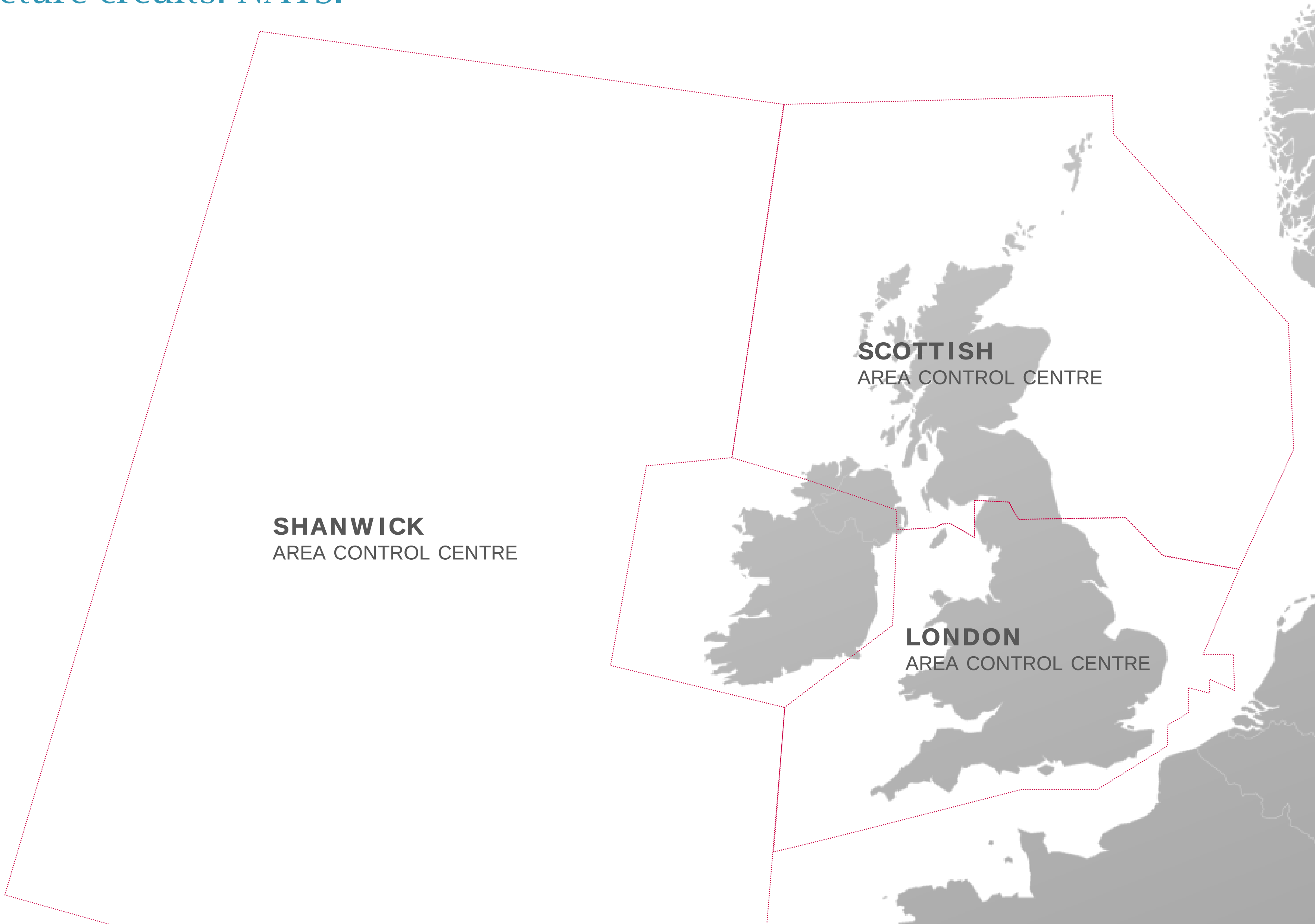
- What is iFACTS?
- Formal Methods – Why Bother?
- Metrics and Issues
- Going Large?
- Conclusions

What is iFACTS?

- iFACTS provides advanced tools support to en-route air-traffic controllers at the London Area Control Centre
  - Trajectory Prediction
  - Medium-Term Conflict Detection
  - Electronic Flight Strip Management
- Or more clearly…

Two Control Centres – Prestwick and Swanwick

Picture credits: NATS.



Swanwick Area

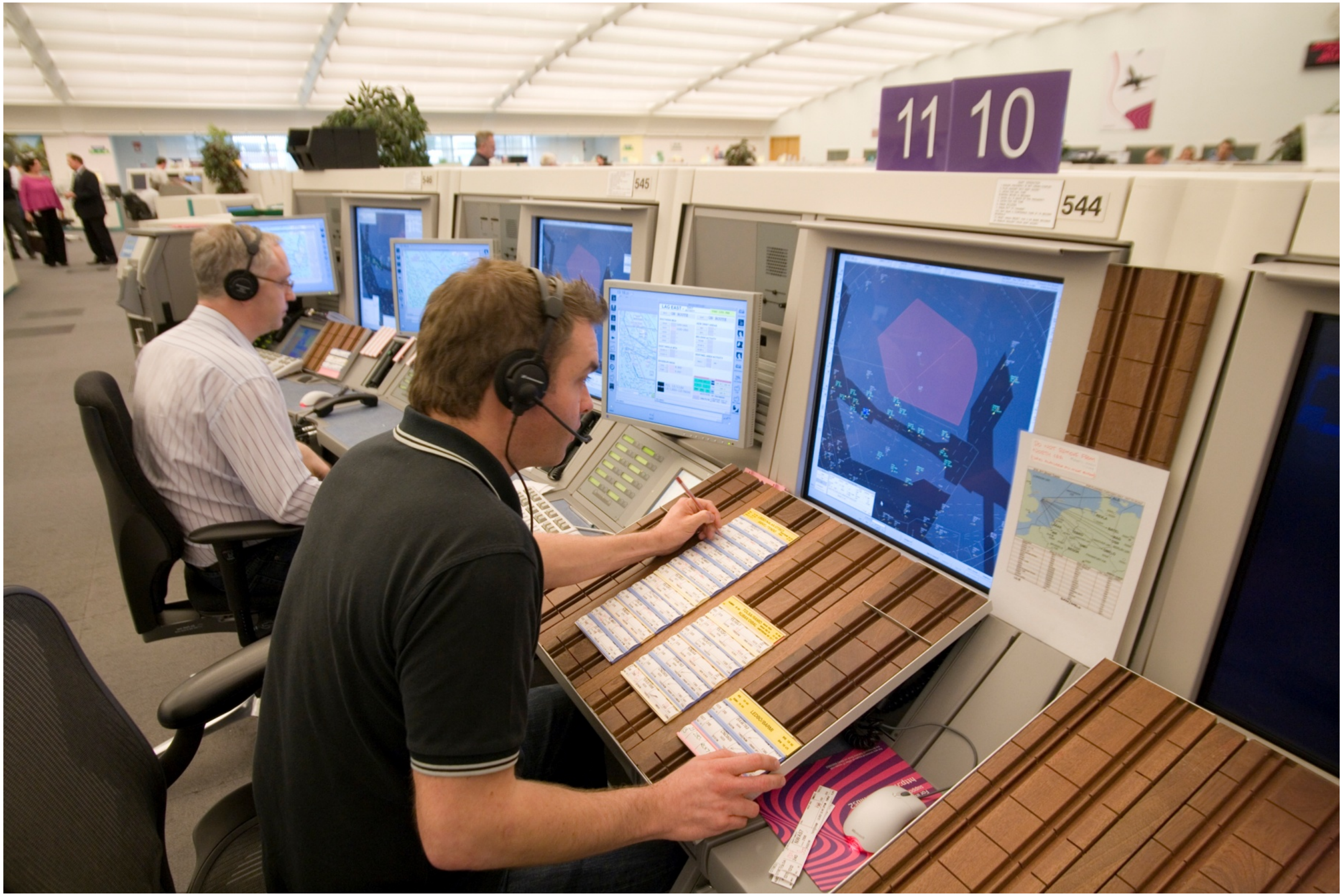
Handles on average **5,500** flights each and every day of the year

Controls **200,000** square miles of airspace above England and Wales including the complex airspace of London

Swanwick Centre

Swanwick Area Control

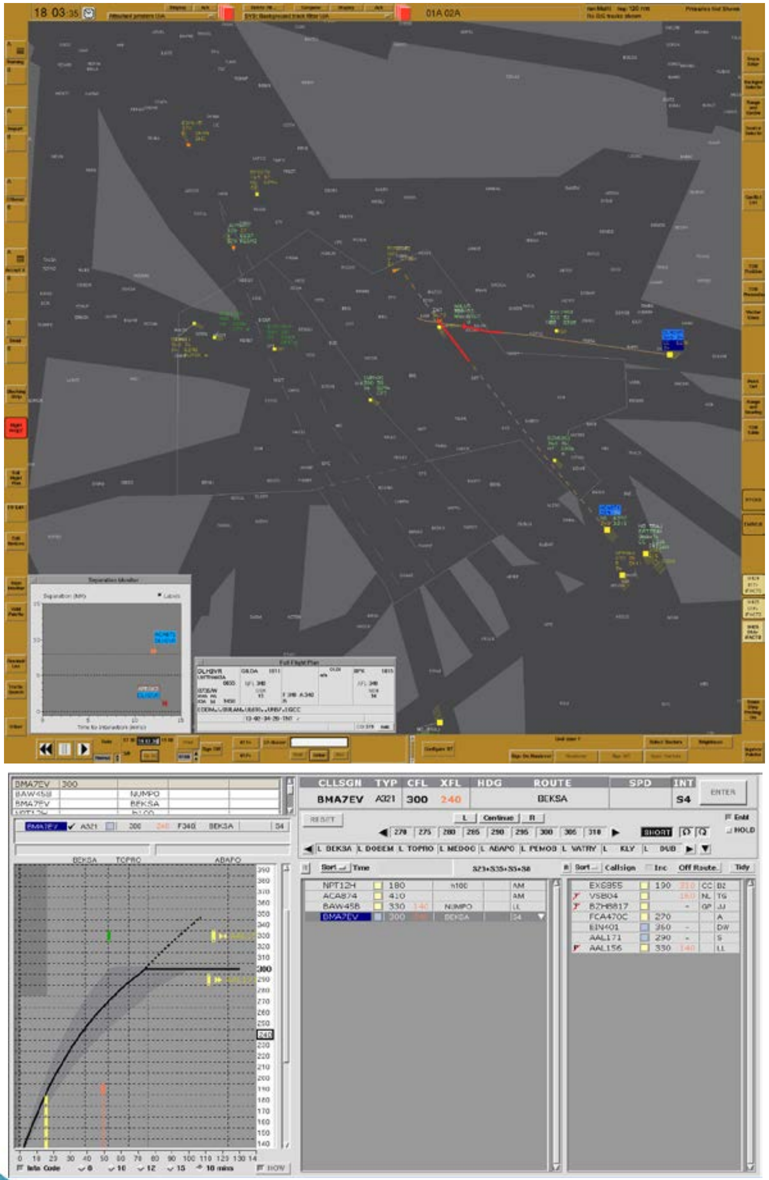
Before iFACTS…

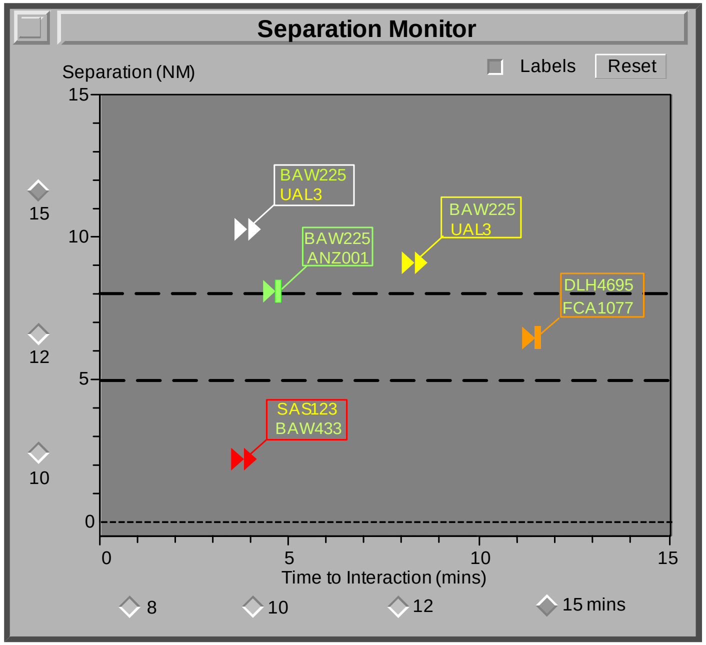


After iFACTS…spot the difference…

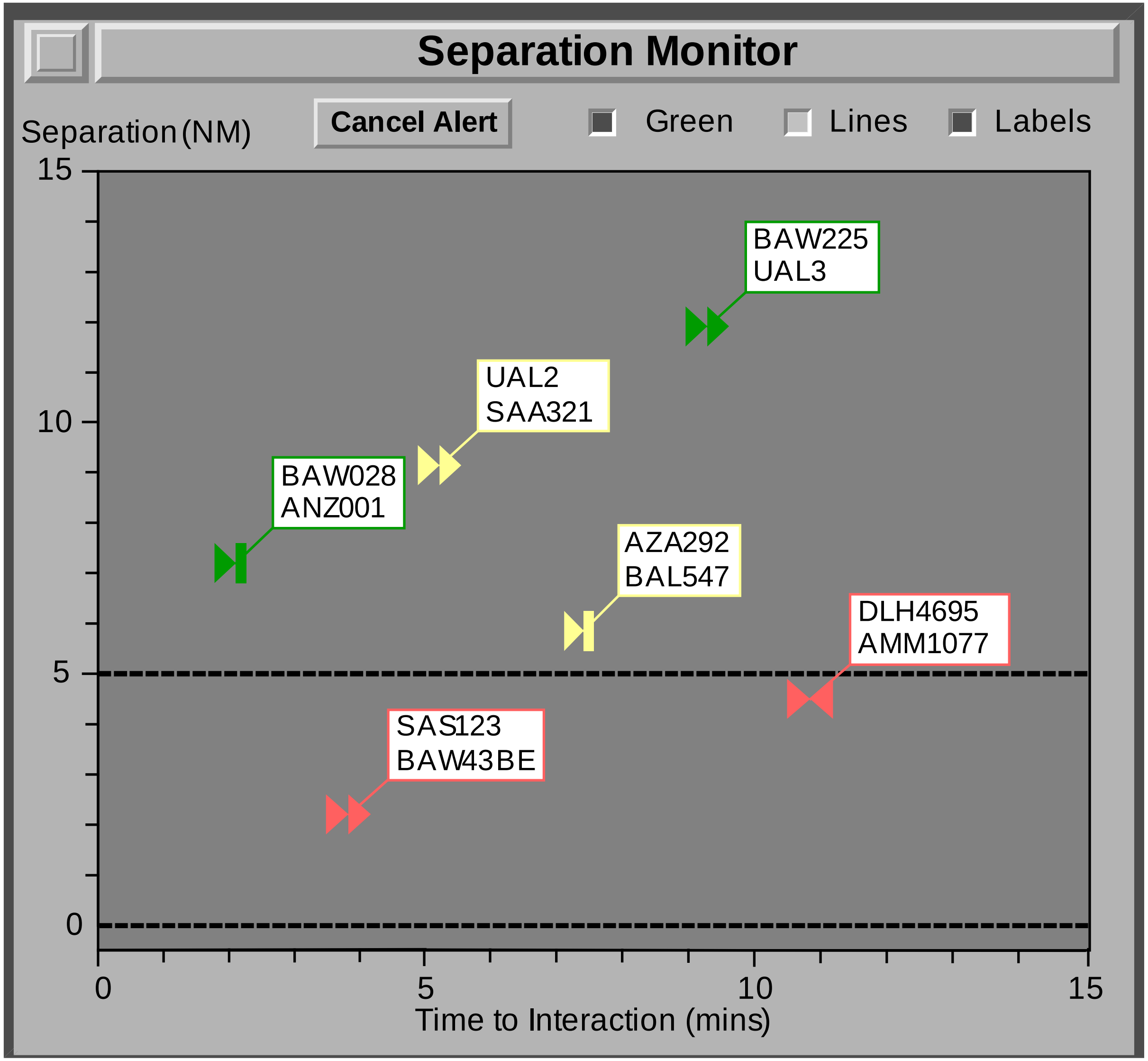
iFACTS Functions

- Advanced electronic prediction and decision support tools.
- Changed method of operation.
- Increased capacity.
- Reduced fuel burn through less interaction.
- Introduction must cause minimal ATC delay and disruption to the 24/7 service.





iFACTS – Medium-Term Conflict Detection: Separation Monitor Window



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Formal Methods on iFACTS

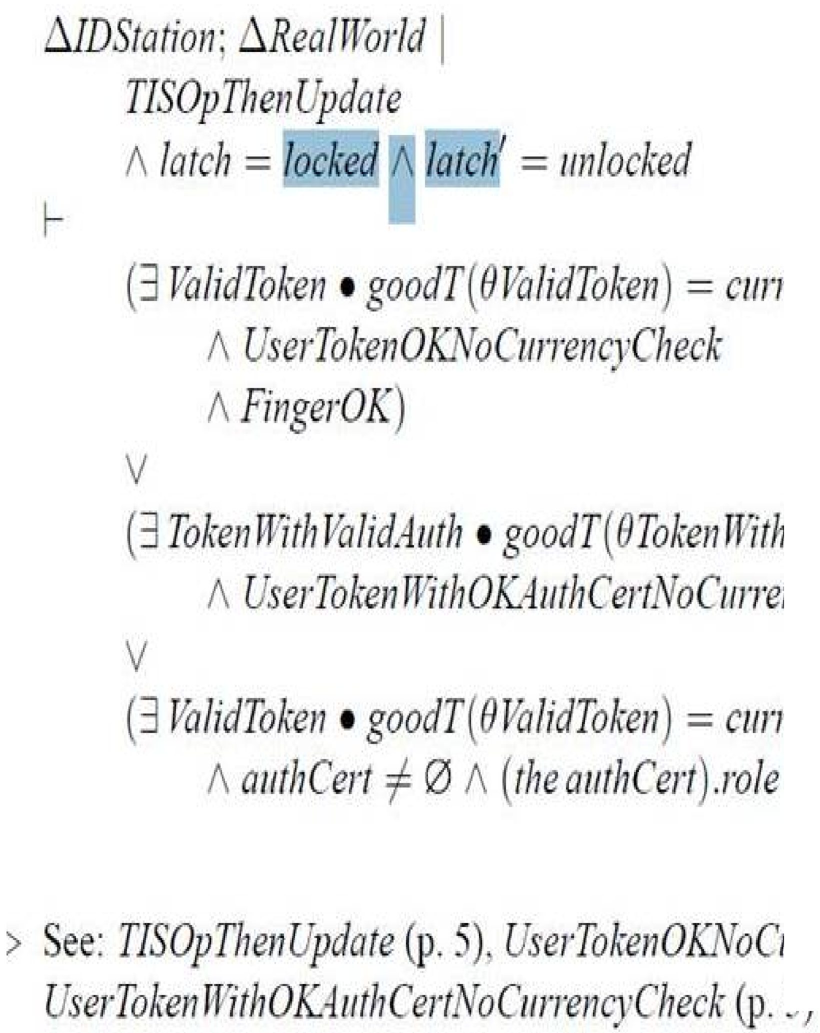
- Two main uses of “Formal Methods” in iFACTS

- Functional Specification in Z with English commentary

- Implementation in SPARK 2005
  - Strong static verification and proof of properties

- Why bother?

So why bother with FM?



$\Delta IDStation; \Delta RealWorld \mid$

$\quad TISOpThenUpdate$

$\quad \land latch = locked \land latch' = unlocked$

$\vdash$

$\quad (\exists ValidToken \bullet goodT(\theta ValidToken) = cur$

$\qquad \land UserTokenOKNoCurrencyCheck$

$\qquad \land FingerOK)$

$\quad \lor$

$\quad (\exists TokenWithValidAuth \bullet goodT(\theta TokenWith$

$\qquad \land UserTokenWithOKAuthCertNoCurre$

$\quad \lor$

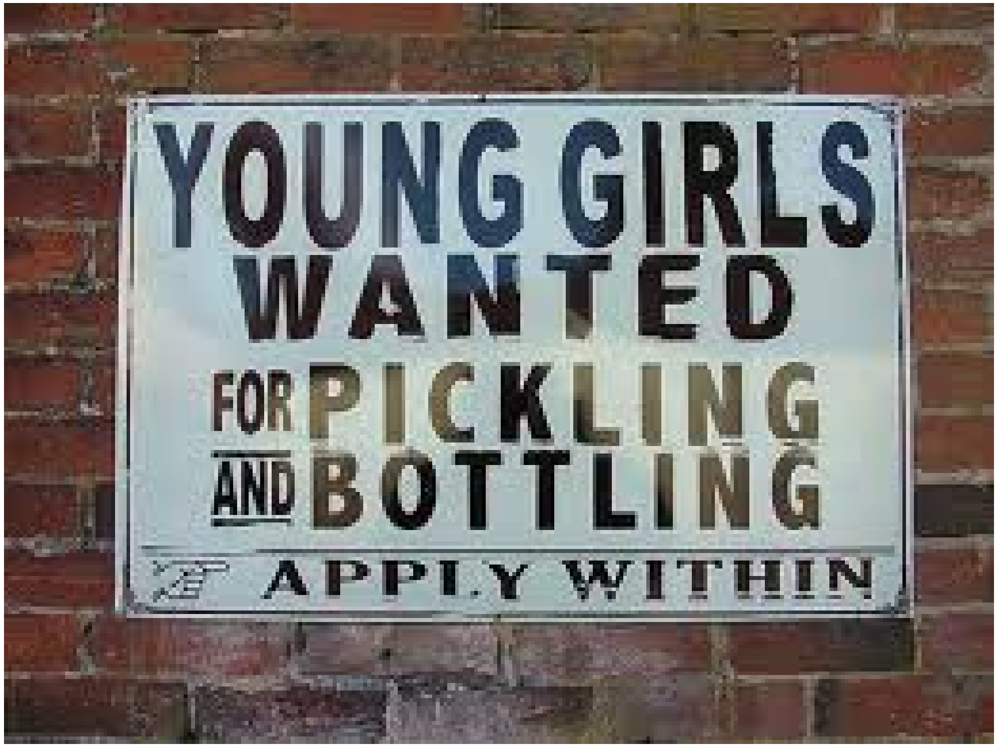
$\quad (\exists ValidToken \bullet goodT(\theta ValidToken) = cur$

$\qquad \land authCert \neq \varnothing \land (the\ authCert).role$

> See: *TISOpThenUpdate* (p. 5), *UserTokenOKNoC*
> *UserTokenWithOKAuthCertNoCurrencyCheck* (p. ..,

So why bother with FM?

Thinking and Tooling Exposes…



Ambiguity…

Thinking and Tooling Exposes…

Contradiction…

Thinking and Tooling Exposes…

Incompleteness…

…particularly *assumptions* that you didn't know about…but really should be written down and validated…

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iFACTS Timeline

- From April 2005 – Requirements Engineering, Formalization and Specification. Still on-going!
- October 2006 – Implementation Project starts
- December 2011 – Fully Operational
  - 24/7 on all sectors with all controllers
- January 2012 and ongoing – Maintenance and upgrades.

Headcount…

- How many “Formalists” do you need?

- Specification team – key “FM skills”
  - requirements elicitation
  - Abstraction
  - Z authoring

- Peak size: 12 people, including 4 NATS employees.

- Now 3 people during maintenance phase.

Headcount…

- How many “Formalists” do you need?

- Implementation team – key “FM skills”
  - *reading Z*
  - test case design
  - SPARK design, implementation and proof.

- Peak size: 130, spread across 4 sites, in 3 timezones.

- Now: 7 people.

Specification Size

- Specification: what do you count?

- We found that “Delta Z” (Added and Modified lines of Formal Text) was an excellent proxy measure that correlated with effort for changes.

- If you printed it all out, the Z functional specification is over 4000 pages.

Training experience

- Z *reader* and *writer* training are separate and very different courses.

- Z Reader Training:
  - 3 day course. We find reasonably fluency after 1 week on the job
  - 57 Engineers trained to read Z, including contractors
  - Also trained NATS Domain Experts and Controllers to read Z so they could review the specification – essential

Training experience

- Z *reader* and *writer* training are separate and very different courses.

- Z Writer Training:
  - 3 day course. Fluent and productive with *3 months* on the job
  - 11 Engineers trained, including NATS staff

Code Size

- Implementation is a mix of
  - SPARK 2005
  - Full Ada (a few modules impractical to write in SPARK – e.g. OS library interfaces)
  - MISRA C (small GUI “Glue” layer)

Code Size

- The SPARK and Ada Code is:
  - 890k “raw” lines of code

  of which

  - 116kloc blank
  - 171kloc comments
  - 74kloc SPARK contracts
  - 529kloc “code”

  of which

  - 250kloc declarations and statements (aka “logical loc”)

SPARK Analyses and Proof

- Data- and Information-Flow
  - No uninitialized variables
  - Verification of intended information flow

- Concurrency
  - No deadlocks
  - No priority inversion or unbounded blocking
  - (See Ada’s “Ravenscar Profile”)

- Memory consumption
  - No pointers, no “heap”, so no worries!
  - Worst case stack usage analysis

SPARK Analyses and Proof

- Proof of “no runtime errors” aka “type safety” in addition to all of SPARK’s type checking rules:
  - Prove no buffer overflow, arithmetic overflow, division by zero etc.

- SPARK Code generates
  - 152927 Verification Conditions

  of which

  - 151026 (98.76%) are proven automatically
  - 1701 proven by a user-defined lemma
  - 200 “reviewed”

SPARK Analyses and Proof

- All coders *must* prove 100% VCs OK *before check-in*.
- *Entire* proof can be reproduced in less than *15 minutes*.
  - Strict Modularity
  - Parallelization (Got 152927 processor cores? Great!)
  - Distributed and persistent caching of proof results.
- "Overnight" proof run clears the cache and rebuilds all analyses and proofs from scratch.

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Going Large?

- So what does “Going Large”? Mean
- For us…the fact that *no one person understands everything* on a project.
- Some have a broad but shallow understanding of the whole system and its context.
- Some have very deep knowledge of some components.

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Conclusions – Formal Methods on iFACTS

- It can be done!
- Tools and Languages must be *designed* to scale up. This does not happen by chance.
- Training people to read and write formal notations is achievable, even for customers.
  - It's only discrete math after all…
  - The notation may seem like a barrier at first, but it's not really.
  - It's the *thinking* that counts.
  - *Abstraction* remains the key skill of system and software engineering.