Applying Formal Methods to a Telecommunications System in a Commercial Setting

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Formal Methods

"The use of mathematical modeling, calculation and prediction in the specification, design, analysis, construction and assurance of computer systems and software."

- Engineering — partial differential equations to model variations in physical quantities over time or space.
- Software — model discrete quantities. Need concepts like sets, graphs, partial-orders, and finite-state machines.
- "Calculation" is in terms of formal logic rather than numerical computation.

FMs in Safety-Critical Systems

"Systems where compelling evidence is required that services are delivered in a manner that satisfies certain critical properties."

Examples:

- Military Systems
- Air Traffic Control Software
- Flight Control Systems
- Nuclear Power Plants
- Medical Systems
- Telephony Networks
- Transportation Systems

How much trust do you have?

CLARINGTON, Ont., April 24 /CNW/ - Ontario Hydro's Darlington Nuclear Generating Station... experienced a spill of moderator heavy water inside the plant...

Without the help of FMs, will the automated nuclear shutdown systems operate as expected?

FMs in Non-Safety Critical Systems

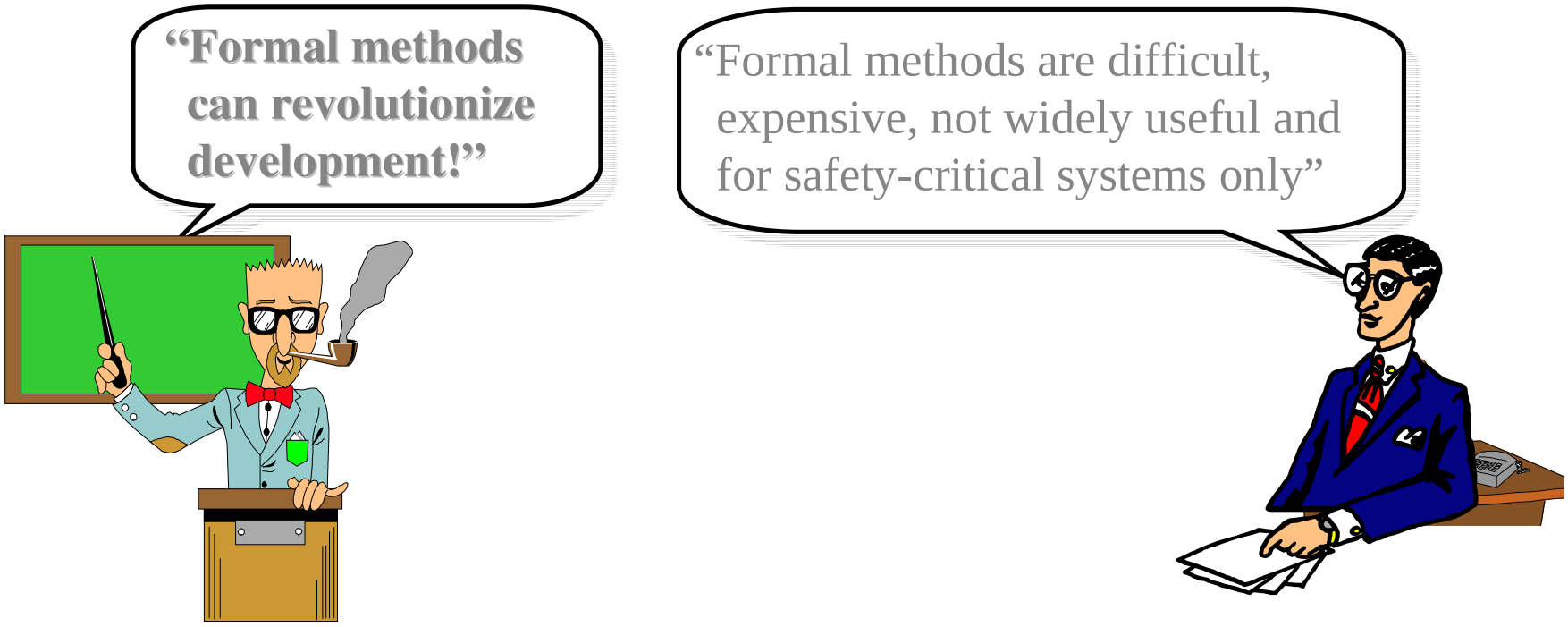
Examples:

- Transaction processing systems
- Databases
- Electronic devices
- CASE tools

Have less impact:

- Smaller scale
- Limited scope
- Adoption rate and % of penetration are much smaller

Why aren't FMs used more?



Why aren't FMs used more? (cont'd)

Myths?

- Require deep mathematical backgrounds
- Are all about proving correctness
- Benefit only the requirements phase
- Always require substantial investments and increase cost
- Are associated with steep learning curves
- Require radical changes to the development process

Incorrect expectations?

- Provide silver bullet for all problems
- Eliminate testing
- Guarantee correct software

Safety-Critical vs Non Safety-Critical

- Goals
  - Cost / Time / Quality
- Nature of the Project
  - Legacy code
  - Need for maintenance
  - Stability of requirements
- Staff
  - Educational background

The Questions

- What are the keys to successful applications of FMs?
  - What essential properties must those FMs have?
  - How should FMs be used?
- What are the improvements/costs?
- What can be done to amortize the cost of creating the formal specifications?
- Is it beneficial to apply FMs to commercial projects? Under what conditions?

The Project

Problem

- Manager of Nortel TorMAC testing team:

  "errors in the requirements specifications are often causing problems in the testing phase."

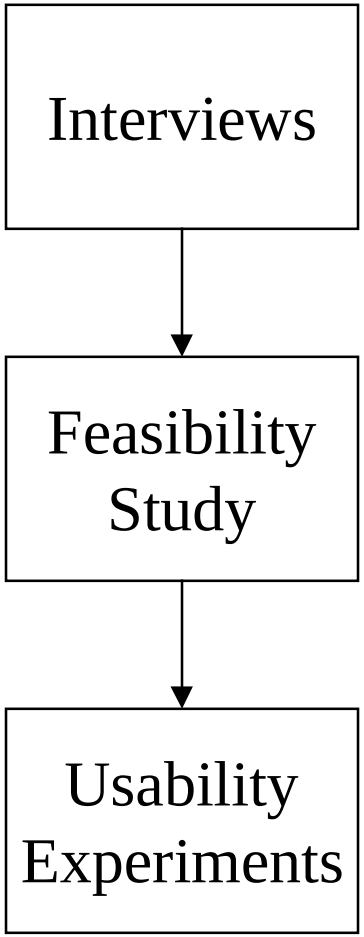
Project

- A collaboration between Nortel and the Formal Methods Laboratory of the University of Toronto

Goals

- Demonstrate feasibility of FMs in telecom systems
- Investigate benefits and problems with applying FMs in a commercial setting

Three Phases of the Project



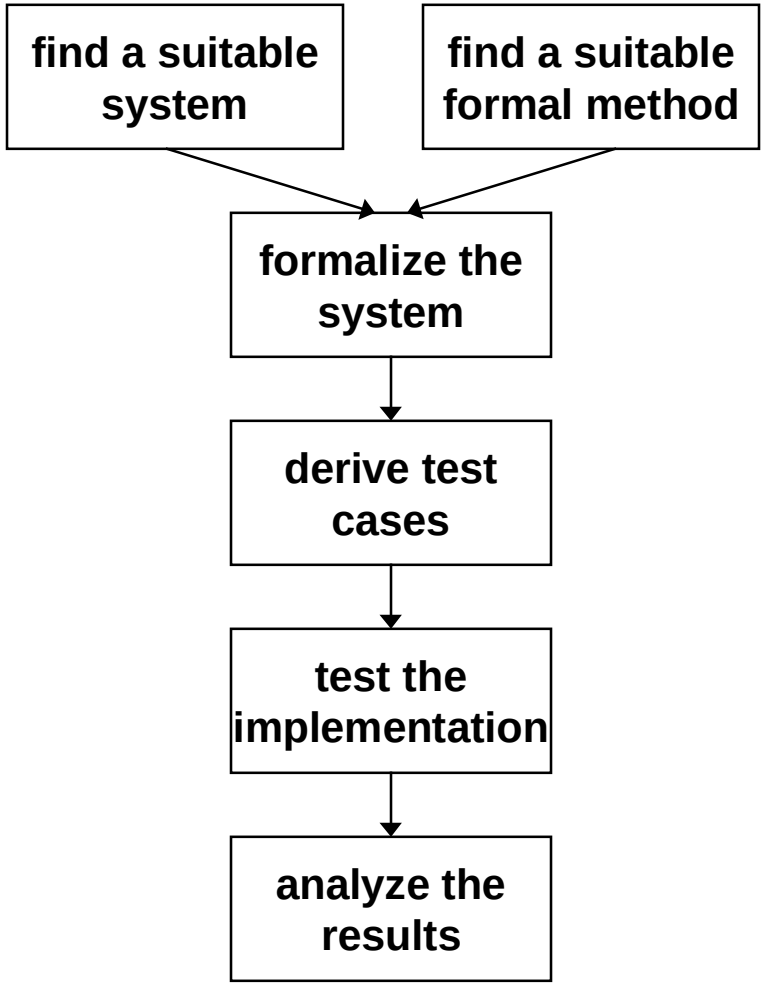
- Conduct interviews to identify problems with development process
- Agree on features of FM
- Model a telecom system using the chosen FM
- Evaluate *effectiveness* of FM vs existing development method
- Evaluate *usability* of the chosen FM by conducting small controlled experiments

Results of Interviews

- Use of prose often causes problems
- Still many errors in the software requirements specifications (SRSs) after several manual inspections
- Errors in the SRSs caused unavoidable design and implementation changes and affected the quality of the test cases created for acceptance testing
- Late changes to the designs and implementations

  → the SRSs and test cases were not always updated

Overview of the Feasibility Study



System Selection

Properties of the Ideal System

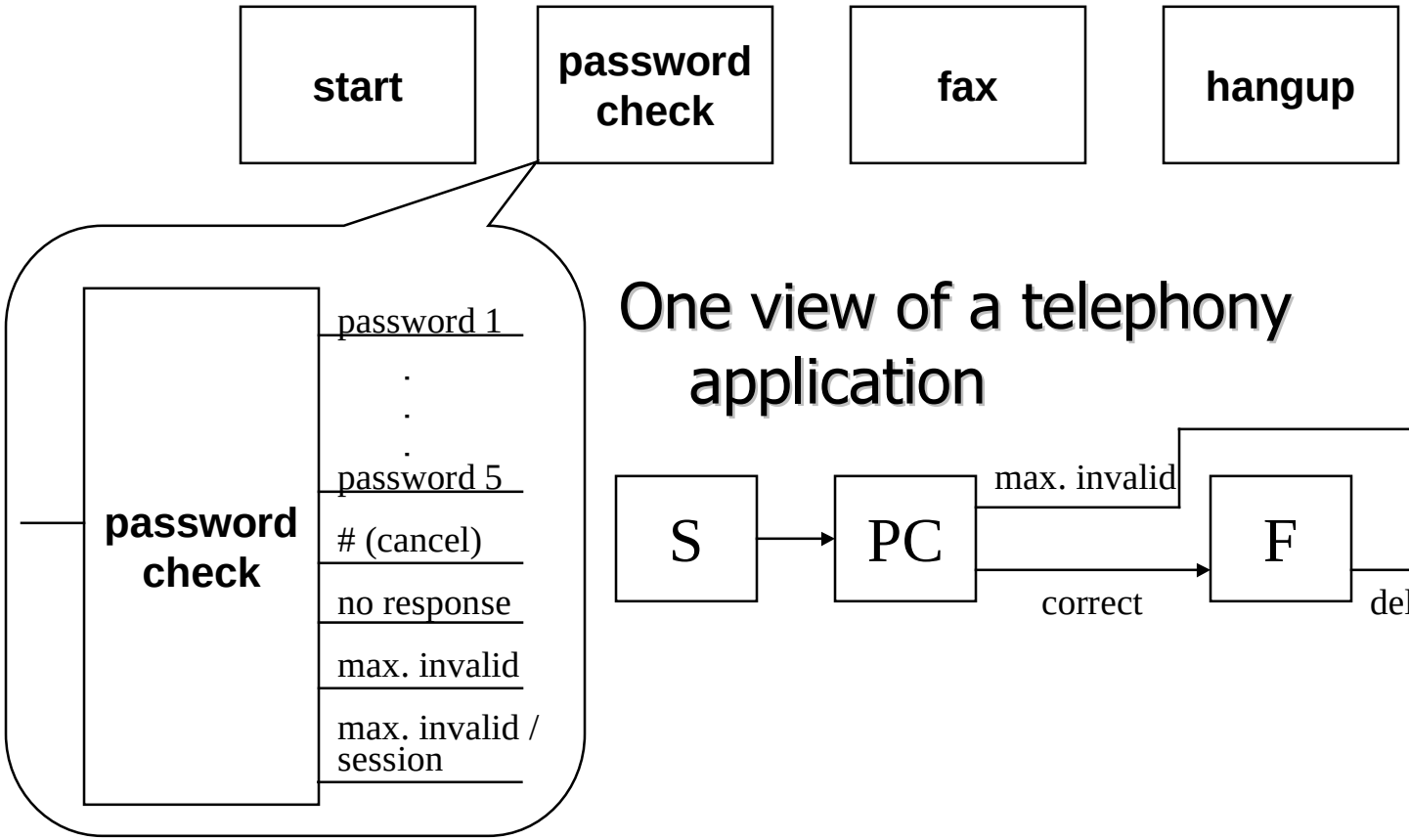
- worth engineering
- self-contained / loosely coupled with the rest of system
- relatively stable requirements
- not too broad in scope but contain complex parts
- reactive

Choose *Service Creator* (SC)

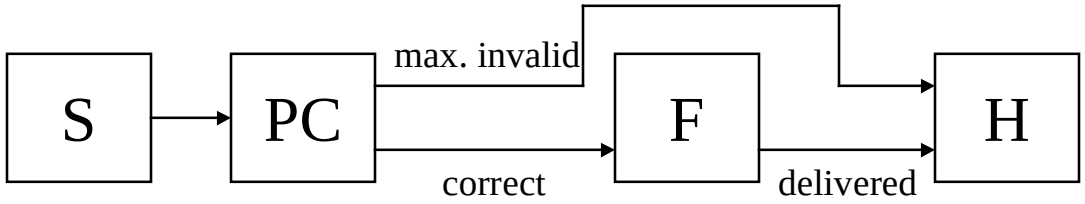
- Voice-service creation environment
- Used for constructing telephony applications through a GUI

System Selection (cont)

Block Run-time Modules (BRMs)



One view of a telephony application



Formal Method Selection

A broad survey to look for FMs that

- have a simple notation
- allow users to produce readable and reviewable artifacts
- provide support for both modeling and testing

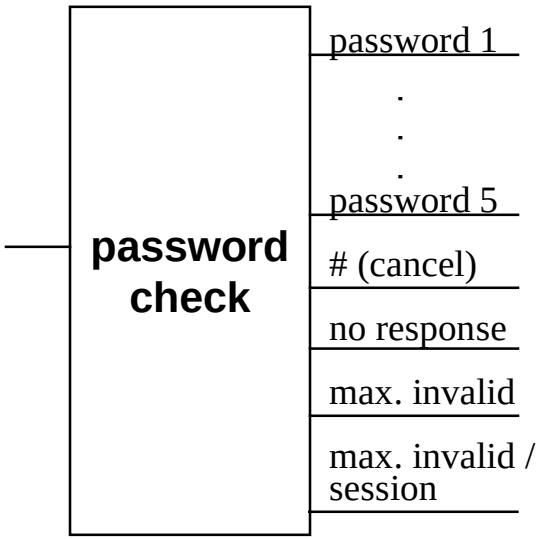
  (for amortizing the cost of creating the formal specification)

Major problems:

- Only a few tools satisfy the last point
- Most research tools are
  - Overkill
  - Too complicated / time consuming

Formal Method Selection (cont)

- Three runners-up:
  - Telelogic SDT
  - Aonix Validator/Req (V/Q)
  - Teradyne TestMaster (T/M)
- Used to model a small part of SC (the password-check component)



Quantitative Feature Analysis

Criteria	Weighting	SDT	V/Q	T/M
has modeling support	5	4	1	3
has testing support	5	3	4	5
has a gentle learning curve	4	3	5	3
produces easy-to-understand artifacts	3	3	5	4
enhances understanding of the system	3	5	3	4
integrates smoothly with the existing development process and tools	4	5	3	3
is scalable	3	4	2	3
has strong industrial support	3	5	4	5
performs completeness or consistency checks	2	3	3	3
provides features such as multi-user support, requirements traceability and document generation	1	3	4	2
Score	**N/A**	**136**	**112**	**124**

SDL

Specification and Description Language (SDL)

- Based on extended finite state machines
- A lightweight formal method (International Telecommunications Union standard Z.100)
- Used in the telecom field (e.g., PBXs and network protocols); now being applied in areas such as aerospace and train control

SDL Tool Support

Features of SDT, the SDL modeling environment

→ Derive MSCs from the model

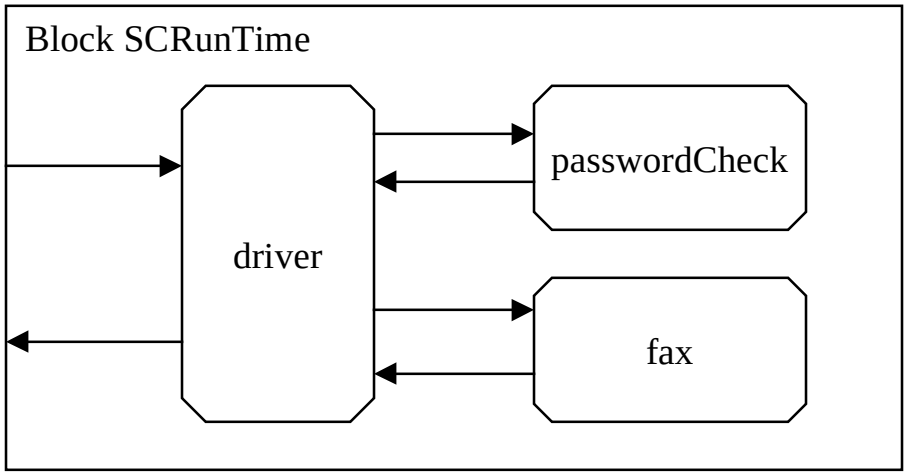
→ Verify MSCs against the model

- Create TTCN conformance test cases (not in our project)
- Check invariant
- Generate code

Modeling the System

- 80 pages of SC specification as a 70-page SDL model
- 10 of the more complicated BRMs → 10 SDL processes
- A 'driver' process administrates the control of the telephony application
- 23 SDL signals (8 external)

The whole SDL system mimics a high-level behavior of a telephony application built by SC.



Level of Abstraction

Modeling is mostly straightforward except for determining the *level of abstraction*

high level of abstraction for simplicity

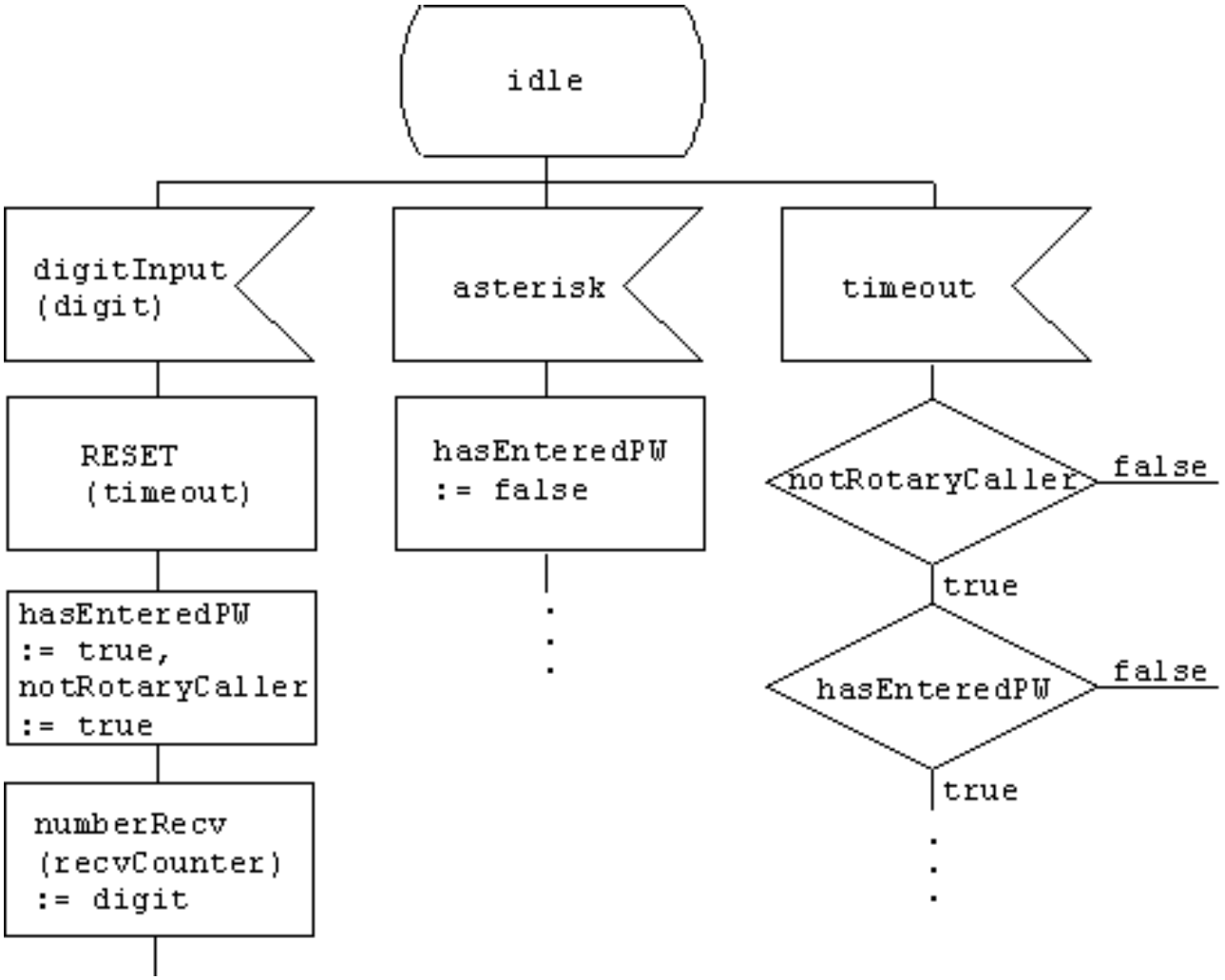
vs

detailed behavioral modeling for deriving sufficiently accurate Message Sequence Charts (MSCs)

Our approach

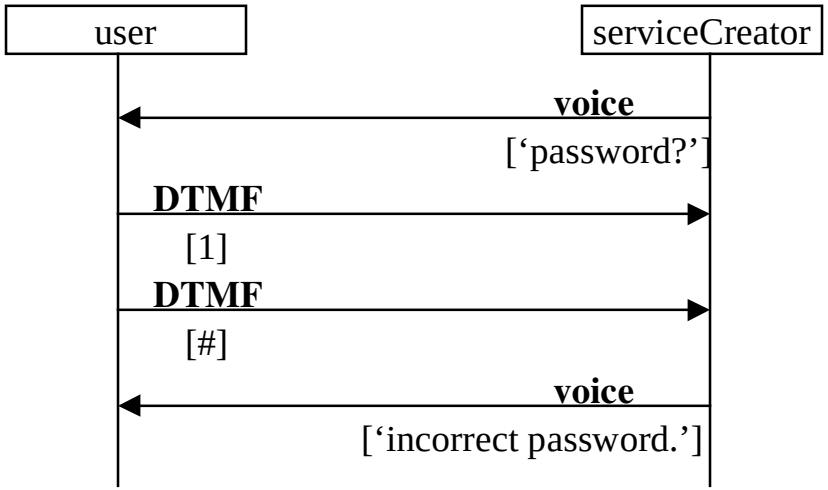
- start with a black-box view
- fill in only the necessary details

Level of Abstraction: Example



Test Case Derivation

- 120 MSCs created
- Creation is not fully automatic



Types of test cases

- Individual
- Component Interactions (more than 20 test cases)

Errors Found

Omissions in the specification (password-check component)

1. Which voice prompts are interruptible?
2. What are the lengths of various timeouts?
3. What are the minimum/maximum # of digits for valid passwords?

Implementation errors

- Some voice prompts are missing
- Rotary callers never get timeouts
- System crashes when passwords are too long

Duration of the Study

The entire study took 3 person-months

- 11 days for creating the models for the BRMs
- 9 days for deriving test cases
- 7 days for executing test cases
- Other activities
  - Choosing the formal method
  - Understanding the specification
  - Solving technical problems
  - Documenting the activities

Quantitative Results

Productivity Data	Study	Existing Process
Time to model (person-days)	11	N/A
# of spec. errors reported	56	N/A
# of test units	269	96
Test unit creation rate (test units/day)	30	21
Test unit execution rate (test units/day)	27	11
# of implementation errors identified	50	23

- Measure data in *test units*
- Some values were comparable
- 18 of 50 implementation errors from the SRS

Qualitative Observations

- Problems in the specification concentrated in a few areas
  - Most were avoidable
  - Most were omissions and vagueness
  - Some led to errors in the implementation
- Benefits of Creating a Model
  - Provide a better understanding of the system
  - More complete SRS → better test coverage
  - Remove errors in the SRS earlier in the development process
  - Aid the design and the testing processes

Changes Required

- Process
  - An add-on → no radical changes
  - Need slightly more time for requirements analysis
  - Require firm commitments from all stakeholders
- Staff
  - Training
  - Model parts of the SRSs in SDL
  - Derive test cases from the model
  - Keep the model and test cases up-to-date

Concerns about FMs

- Need careful application
- Are applicable only to some types of systems
- Require some changes to the existing development process
- Increase requirement cost
- Demand commitments from both the design and the testing teams
- How usable?

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Lessons from the Study

- FMs can be applied to commercial systems effectively
- A successful application of a FM depends on
  - Choice of the system to be modeled and a suitable formal method
  - Careful use of the FM and its tool
  - Established plan for a smooth integration
  - Commitments from stakeholders
  - Reasonable expectations from the FM
  - Availability of on-site "champions"

Current Work

- Usability of SDT/SDL
  - Experiment with Nortel engineers
    - Effective use of the SDL framework
    - Perceived usability problems
  - Surveys to collect opinions of Nortel engineers
    - Usefulness/impact of using the SDL framework
    - Integration problems

Future Work

- Pilot study by Nortel engineers
  - SDL integrated into the development process
  - More SDL modeling: a larger part of SC
  - Progress monitoring: time/cost/quality
  - Researchers act as observers and consultants