Formal Methods for Verifying the Singularization Strategy: a Work-in-Progress on a bilateral project

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Introduction to Singularization

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- Reduce vulnerability of encryption of embedded systems: Improving DES
- Improve security of legacy Sim Cards

In both cases the system is strengthened by introducing a larger variety in the system to attack and therefore making it harder to pick the correct attack, much like in MTD.

Improving DES: A case study

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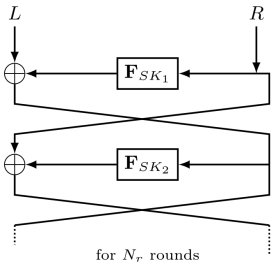
Singularization tackles this problem by introducing a set of pseudo-random functions (PRF), which are chosen at random for each round.

By enlarging the set of PRFs, there can be as many variations as there are (56bit) keys, mitigating differential attacks:
[1]: Singularization: A New Approach to Designing Block Ciphers for Resource-Constrained Devices, G. Macario-Rat, M. Plesa



DES from a formal point of view

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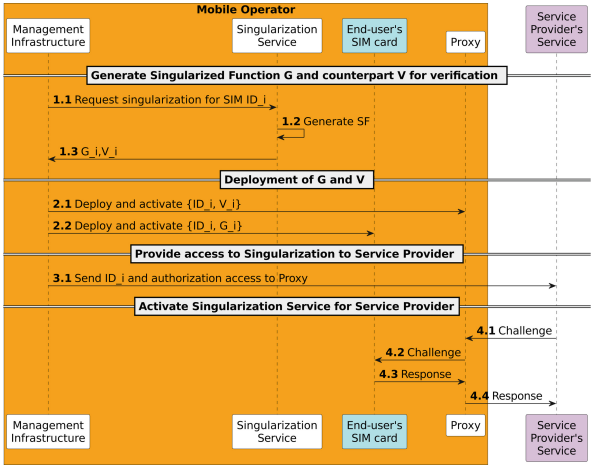
Automata-based approaches do not lend themselves very well to answer secrecy related questions, like “Is the system vulnerable to cryptanalysis?”

Part of the problem is the state-space explosion, the other part is due to the problem of translating the question into graph properties.

Using singularization within an application

In [6], a framework of how to use singularization within a protocol is presented.

Position Paper: Strengthening Applets on Legacy SIM Cards with Singularization, a New Moving Target Defense Strategy, Gaber *et al.*



Verification of Concurrent and Distributed Systems

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In this talk we will paint a broad overview of techniques and tools applicable to such problems.

Where formal methods have been used successfully

Transport Layer Security (TLS) 1.2

Long list of security issues

- No forward secrecy
- Downgrade Attacks
- Insecure Renegotiation
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- ProVerif language is based on Pi calculus
- It supports the definitions of types, functions, and equations
- Security properties are then reduced to consistency checks and resolution / reachability

ProVerif Example - Denning-Sacco

Definition of primitives

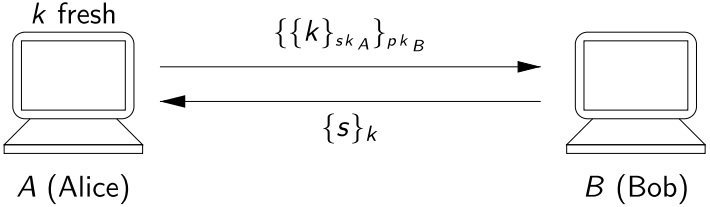
```
free c.
(* Public key cryptography *)
fun pk/1.
private fun sk/1.
(* just encryption, no signing *)
fun encrypt/2.
reduc decrypt(encrypt(x,pk(y)),sk(y)) = x.
(* Symmetric key cryptography *)
fun symcrypt/2.
reduc symdecrypt(symcrypt(z,j),j) = z.
```

Usage within the protocol

```
let processB =
    in(c,m1);
    let (na,Y) = decrypt(m1, sk(B)) in
    new Nb;
    out(c, encrypt((na, Nb), pk(Y)));
    in(c,m3);
    let (=Nb) = decrypt(m3, sk(B)) in
    (*...*)
```

ProVerif Example - Denning-Sacco cont'd

Denning-Sacco Intent



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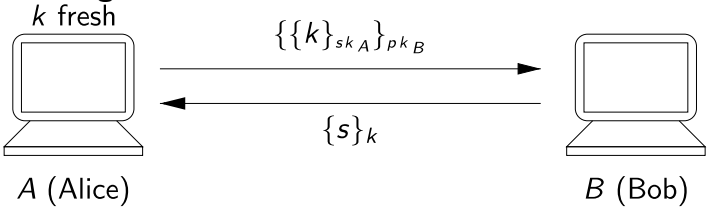
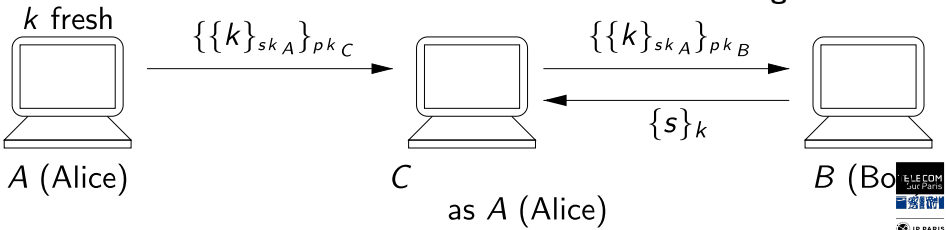


Denning-Sacco Fail



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- ⊖ Blackbox cryptography
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One step further: Proving protocols written in (a large fragment of) Rust using hax.

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Much like ProVerif it also performs a symbolic analysis, however they introduced the concept of interactive theorem proving.
Interactive theorem proving allows to insert dedicated lemmas "unblocking" the prover, however this idea has since been largely picked up by ProVerif as well.

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For our project, tamarin seems to play a very similar role to ProVerif.

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The tool has been used to verify TLS 1.3, the model is available and maintained.

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- Good tooling and trace extraction
- Decomposition into games makes it extensibly
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Approach seems to be well suited for singularization.

(III) Automata Theoretic Approaches - Analysing MTD Strategies

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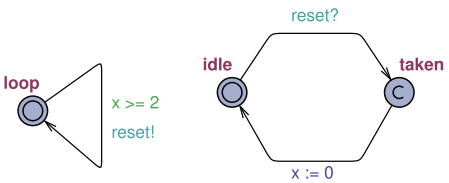
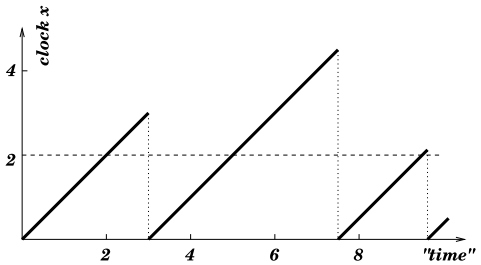
Priced Timed Markov Decision Processes (PTMDP)

(III) Automata Theoretic Approaches - UPPAAL SMC & Stratego

A quick introduction - Timed Automata!
Timed automata are a well known formalism for modeling real-time systems.
They augment finite state machines with clocks.
UPPAAL adds many common features like synchronization, data variables, and more.





reachability, deadlock-freedom, fastest path, fragment of CTL
https://uppaal.org/texts/small_tutorial.pdf

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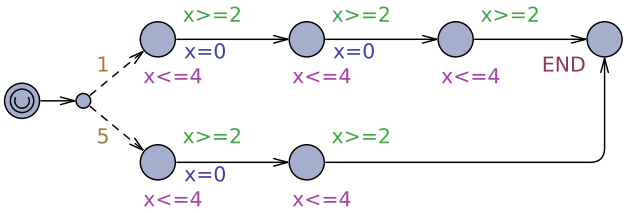
Introducing **SMC**: Statistical Model Checking for Timed Automata.

UPPAAL SMC allows to reason about the probability of a certain path being taken, with guarantees on the obtained distribution.
`https://uppaal.org/texts/uppaal-smc-tutorial.pdf`



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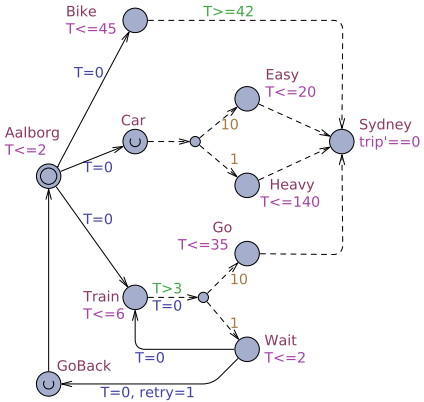

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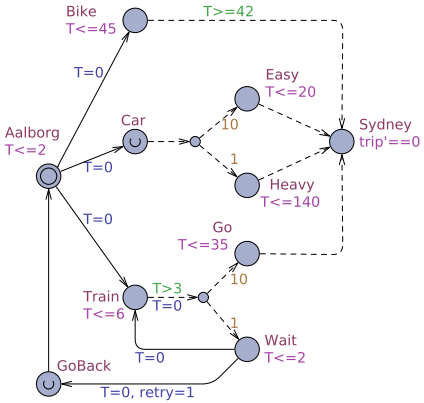

Allows to synthesize strategies minimizing the expected cost under (probabilistic) safety constraints.

- **GoSafe**: Reach Sydney in less than 60 minutes
- **GoFast**: Minimize the expected travel time
- **GoFastAndSafe**: Minimize and guarantee

Uppaal SMC & Stratego

- ⊕ Probabilistic reasoning
- ⊕ Synthesis of strategies
- ⊕ Allows to reason about cost and benefits
- ⊕ Principled way to work with Attack Trees
- ⊕ Good tooling and trace extraction

- ⊖ "Model-based"-reasoning, no direct way to translate protocols
- ⊖ Secrecy and authentication properties are harder to model
- ⊖ Abstract model, no support for cryptographic primitives

Thank you for your attention!
I'm happy to take your questions!

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