AVATAR: A SysML Environment for the Formal Verification of Safety and Security Properties

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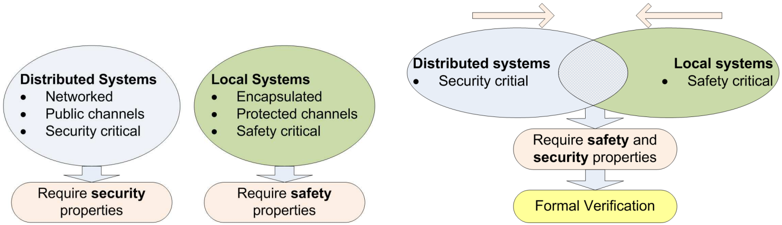
Outline

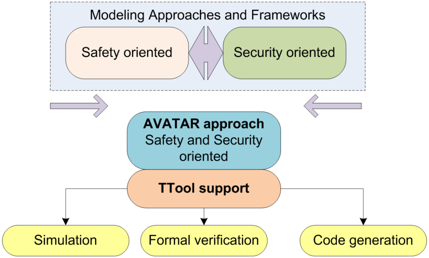
Context
main concerns

Tendency in embedded systems design



Context
main concerns

- Modeling approaches target either
  - safety properties or
  - security properties
- Safety and security models should be maintained
- Consistency problems



Methodology Phases

Overview

Requirements capture: Models requirements to be satisfied, e.g. with Requirement Diagrams

System analysis: Analysis of system behavior, e.g. using Sequence Diagrams

System design: Captures system behavior, e.g. with AVATAR profile

Property modeling: Captures properties to be verified, e.g. in TEPE Diagrams [1]

Formal verification: Formal proves over targeted properties

Refinement: Repeat previous stages adding system elements up to final design

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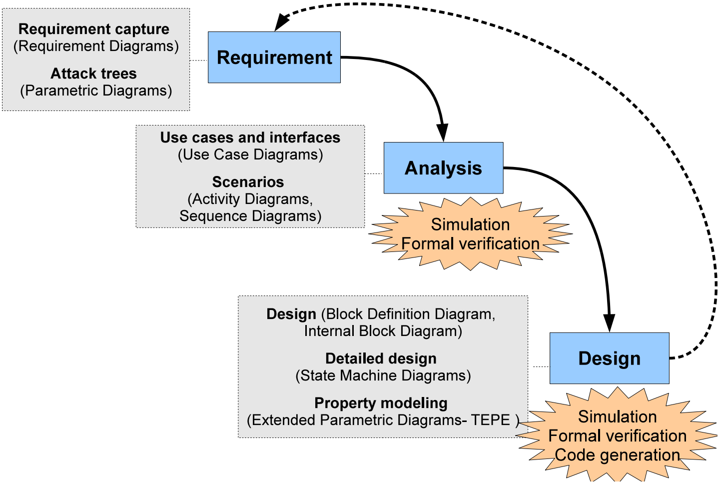
[1] See [1]

Methodology Phases

Implementation

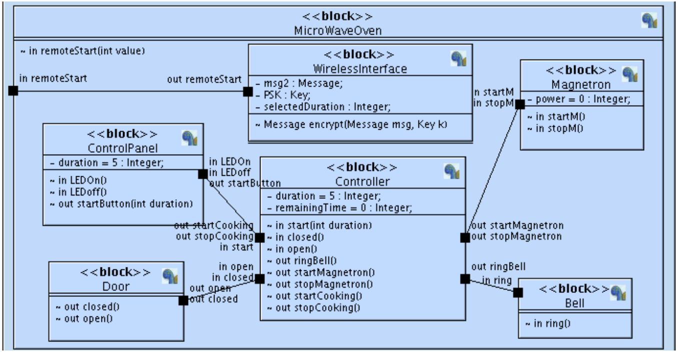


AVATAR
In a Nutshell

- SysML environment supporting all methodological phases
- Graphical capture of properties
- Integrated simulation
- Safety and **security** proofs at the push of a button
- C-POSIX code generation

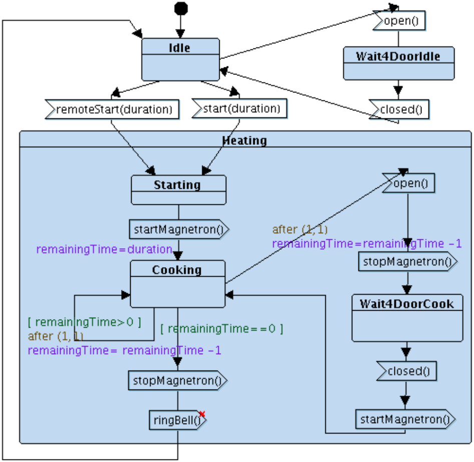
Design: Architecture

- SysML Block Definition and Internal Block Diagrams
- Block = attributes, methods, in/out signals, behaviour



Detailed Design

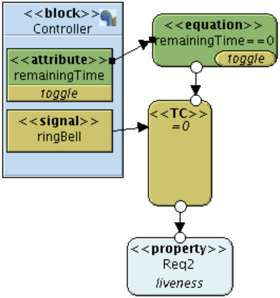
- Block's behaviour is described in terms of SysML State Machine Diagrams
- Non deterministic choices
- Non deterministic temporal operators



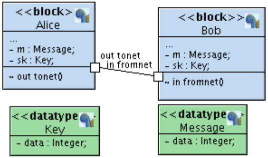
Property Modeling

Security properties

- Customized Parametric Diagrams (TEPE)



Profile limitations
to address security



Initial knowledge: No way to preshare data between blocks

Cryptographic functions: Not predefined and should be modelled

Communication Architecture: Channels can not be eavesdropped

Attacker model: Not included and not easily representable

Security properties: Not easily representable

AVATAR for security

implemented extensions

Initial knowledge: Introduced as a common knowledge by the pragma:
#InitialCommonKnowledge *Alice.sk Bob.sk*

Cryptographic functions: Predefined in each crypto block: *MAC(), encrypt(), decrypt(), sign(), verifyMAC(), verifySign()...*

Communication Architecture: Common broadcast channels can be defined in blocks. Attackers can eavesdrop public ones

Attacker model: Taken from the underlying security framework *ProVerif*[2]

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AVATAR for security
implemented extensions

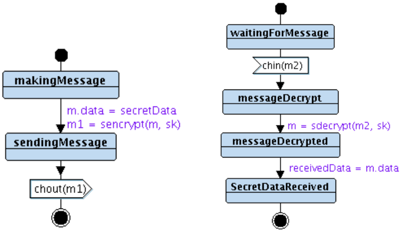
Security properties: **Confidentiality** of *data* intended to be secret is captured in the pragma:

***#Confidentiality** Alice.sk*

Authenticity of a block exchange is captured in the pragma:

***#Authenticity** Alice.sendingMessage.m1*

Bob.messageDecrypted.m2



a – Alice   b – Bob

Why ProVerif?

as underlying formal framework

- Proverif is [3] ...
  - quite generic: targets communicating systems modeling in general
  - completely automated
  - well suited for communicating entities (CEs) modeling:
    - based upon process algebras
    - CEs represented as pi-processes
  - oriented to prove security properties:
    - confidentiality
    - authenticity
  - endowed with an attacker targeting security properties
  - supported by a rigorous formal approach
  - implemented with a resolution algorithm

[3] See [2]

Processes
in ProVerif

Syntax of the process calculus [4]

`M,N::=`		terms
	`x,y,z`	variables
	`a,b,c,k`	names
	`f(`$M_1 \ldots M_n$`)`	constructor application
`P,Q::=`		processes
	`out(c,M); P`	outputs *M* in *c* then *P*
	`in(c,M); P`	inputs *M* from *c* then *P*
	`new a; P`	defines *a* restricted to *P*
	`event myEvt(x); P`	executes an event *myEvt(x)* then *P*
	`let x=g(`$M_1 \ldots M_n$`) in P else Q`	destructor application
	`if M=N then P else Q`	conditional
	`P|Q`	parallel composition of processes *P*, *Q*
	`!P`	infinite replication of process *P*
	`0`	null process

[4] See [3]

Properties
in ProVerif

Defined as queries [5]:

Confidentiality: can the attacker disclose secret data -*mySecret*?

```
query attacker:mySecret
```

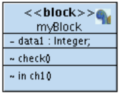
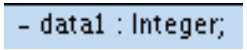
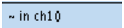
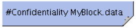
Authenticity: can the attacker break the receiver-sender correspondence?

```
query evinj:eventReceiveM(x)==>evinj:eventSendM(x)
```

[5] See [3]

AVATAR block diagram to ProVerif

Translation rules

AVATAR	ProVerif	Semantics
Block declaration 	`let` $myBlock_0$=	The initial process $myBlock_0$
Block data types 	`new` *`data1`*`;`	The new name *`data1`*
Block input signal 	`free` *`ch1`*.	The input channel *`ch1`*. Quite similar rule for *`output`* or *`private`* channel
Common knowledge *val* in blocks $\{B_i\}$ 	`new` *`val`*`;`	The static variable *`val`* is only known by the processes $\{Block_i\}$, *i=1...n*
Confidentiality pragma 	`query attacker:` *`data`*.	*`data`* confidentiality will be proved

Formal Proves

Security Properties

Performed at a push of a button!

Here the process[6]:

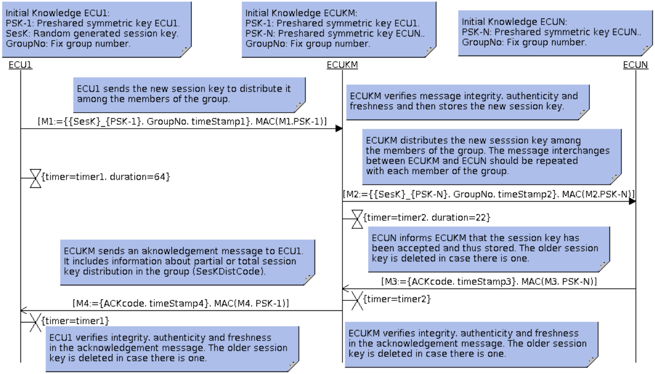
1. Translation of AVATAR model to ProVerif
2. Gained attacker knowledge in form of Horn clauses
3. Confidentiality; for each `query attacker:mySecret` the attacker:
   - builds a finite inference space of horn clauses
   - searches whether `mySecret` can be inferred
4. Authenticity; for each `query evinj:eventReceiveM(x)==>evinj:eventSendM(x)` the attacker:
   1. test all input channels
   2. acts on behalf of sender - or receiver - in replicated sessions
   3. builds a finite space of horn clauses
   4. proves sender-receiver correspondence

[6] See [4]

Keying Protocol

EVITA project

Security Goal: distribute a new secret key amongst members of a group of in-car Electronic Control Units (ECUs).[7]

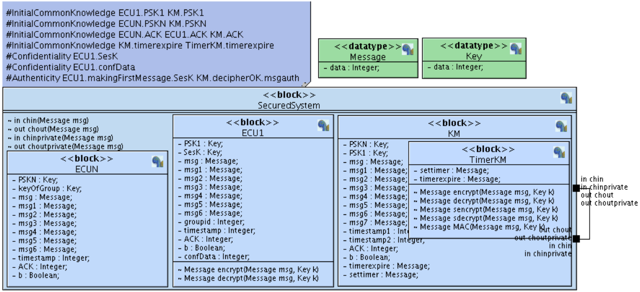


[7] See [5], [6]

AVATAR model of Keying Protocol

EVITA project

- Each ECU associated to a crypto block
- Public input and output channels
- Predefined crypto functions are used: *sencrypt(), sdecrypt, MAC(), etc.*
- Confidentiality of *SesK* and mutual authentication (`<auth>`) of ECUs is required



Results
Security proofs

Keying Protocol verification results[8]

Verification Scheme	AVATAR model and pragmas
Modeled Blocks	*ECU1, ECUKM, ECUN*
Verified confidential data	*SesK, PSK-1, PSK-N*
Verified authenticity correspondences	*ECU1*<auth>*ECUKM*, *ECUKM*<auth>*ECUN*
RESULT #*Confidentiality* B.dat	True for each verified data *dat*
RESULT #*Authenticity* B_d.Send.Mx B_o.Valid.Mx	True for each correspondence and message *Mx*
Observations	Keying Protocol preserves data confidentiality and authenticity.

8 See [7]

Conclusions

- AVATAR:
  - eases embedded systems modeling
  - easily proves safety and security properties
  - avoids models consistency maintainability
  - is fully supported by TTool[9]
  - has been tested in industrial projects
- However:
  - only targets confidentiality and authenticity
  - not suitable for temporal analyses
  - richer notions of attackers are required

[9] See [8]

Next steps
to do

- introduce temporal analyses capabilities
- introduce richer notions of attackers:
  - to prove message integrity
  - to prove message freshness
- automatic code generation from models
- code maintainability
- addapt tool support

Thanks

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