

# Modelling Software-based Systems

## Lecture 4

### System Engineering using Refinement-based Methodology

Master Informatique

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# General Summary

- 1 Refinement of models
- 2 Summary on Event-B
- 3 The Access Control
- 4 Conclusion

- 1 Refinement of models
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- Refinement relates Event-B models
- Problem for starting a refinement-based development
- Problem for finding the best abstract model
- Problem for discharging unproved proof obligations generated for each refinement step
- The Access Control Problem

## Current Summary

- 1 Refinement of models
- 2 Summary on Event-B
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# Simple Form of an Event

- An event of the **simple** form is denoted by :

$\begin{aligned} < event\_name > \hat{=} \\ & \text{WHEN} \\ & \quad < condition > \\ & \text{THEN} \\ & \quad < action > \\ & \text{END} \end{aligned}$
--

where

- $< event\_name >$  is an identifier
- $< condition >$  is the firing condition of the event
- $< action >$  is a generalized substitution (**parallel** “assignment”)

# Non-deterministic Form of an Event

- An event of the **non-deterministic** form is denoted by :

```
< event_name > ≡  
  ANY < variable > WHERE  
    < condition >  
  THEN  
    < action >  
  END
```

where

- < *event\_name* > is an identifier
- < *variable* > is a (list of) variable(s)
- < *condition* > is the firing condition of the event
- < *action* > is a generalized substitution (**parallel** “assignment”)

# Shape of a Generalized Substitution

A generalized substitution can be

- **Simple** assignment :  $x := E$
- **Generalized** assignment :  $x : P(x, x')$
- **Set** assignment :  $x : \in S$
- **Parallel** composition : 
$$\begin{array}{c} T \\ \dots \\ U \end{array}$$



$$\text{INVARIANT} \wedge \text{GUARD} \implies \text{ACTION establishes INVARIANT}$$

# Invariant Preservation Verification (1)

- Given an event of the simple form :

```
EVENT e ≡  
  WHEN  
    G(x)  
  THEN  
    x := E(x)  
  END
```

and invariant  $I(x)$  to be preserved, the statement to prove is :

$$I(x) \wedge G(x) \implies I(E(x))$$

# Invariant Preservation Verification (2)

- Given an event of the simple form :

EVENT  $e \triangleq$   
WHEN  
     $G(x)$   
THEN  
     $x : |P(x, x')$   
END

and invariant  $I(x)$  to be preserved, the statement to prove is :

$$I(x) \wedge G(x) \wedge P(x, x') \implies I(x')$$

# Invariant Preservation Verification (3)

- Given an event of the simple form :

```
EVENT e ≡  
  WHEN  
    G(x)  
  THEN  
    x :∈ S(x)  
  END
```

and invariant  $I(x)$  to be preserved, the statement to prove is :

$$I(x) \wedge G(x) \wedge x' \in S(x) \implies I(x')$$

# Invariant Preservation Verification (4)

- Given an event of the non-deterministic form :

```
EVENT e  $\hat{=}$   
  ANY v WHERE  
    G(x, v)  
  THEN  
    x := E(x, v)  
  END
```

and invariant  $I(x)$  to be preserved, the statement to prove is :

$$I(x) \wedge G(x, v) \implies I(E(x, v))$$



## Refinement Technique (2)

- Some **new events** may appear : they refine “skip”
- Concrete events **must not block more often** than the abstract ones
- The set of new event alone **must always block eventually**

# Correct Refinement Verification (1)

- Given an **abstract** and a corresponding **concrete** event

```
EVENT ae ≐  
  WHEN  
    G(x)  
  THEN  
    x := E(x)  
  END
```

```
EVENT ce ≐  
  WHEN  
    H(y)  
  THEN  
    y := F(y)  
  END
```

and invariants  $I(x)$  and  $J(x, y)$ , the statement to prove is :

$$I(x) \wedge J(x, y) \wedge H(y) \implies G(x) \wedge J(E(x), F(y))$$



# Correct Refinement Verification (2)

- Given an **abstract** and a corresponding **concrete** event

```
EVENT ae ≐  
  ANY v WHERE  
    G(x, v)  
  THEN  
    x := E(x, v)  
  END
```

```
EVENT ce ≐  
  ANY w WHERE  
    H(y, w)  
  THEN  
    y := F(y, w)  
  END
```

$$\begin{aligned} & I(x) \wedge J(x, y) \wedge H(y, w) \\ \Rightarrow & \\ & \exists v \cdot (G(x, v) \wedge J(E(x, v), F(y, w))) \end{aligned}$$

# Correct Refinement Verification (3)

- Given a NEW event

```
EVENT ce ≐  
  WHEN  
    H(y)  
  THEN  
    y := F(y)  
  END
```

and invariants  $I(x)$  and  $J(x, y)$ , the statement to prove is :

$$I(x) \wedge J(x, y) \wedge H(y) \implies J(x, F(y))$$

## Current Summary

- 1 Refinement of models
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- 3 The Access Control**
- 4 Conclusion

# A Case Study by J.-R. Abrial

- To control **accesses** into locations.
- People are assigned certain **authorizations**
- Each person is given a **magnetic card**
- Doors are “one way” **turnstyles**
- Each turnstyle is equipped with :
  - a **card reader**
  - two **lights** (one **green**, the other **red**)



# Access Protocol (after introducing card in reader)

- If access **permitted** {
  - green light **turned on**
  - turnstyle **unblocked for 30 sec**
- Passing, or 30 sec elapsed {
  - green light **turned off**
  - turnstyle **blocked** again
- If access **refused** {
  - red light **turned on for 2 sec**
  - turnstyle **stays blocked**

## Goal of System Study

- Sharing between **Control and Equipment**
- For this : constructing a **closed model**
- Defining the **physical environment**
- Possible **generalization** of problem
- Studying **safety** questions
- Studying **synchronisation** questions
- Studying **marginal** behaviour

# Basic System Properties

P1 : The model concerns **people** and **locations**

P2 : A person is authorized to be in **some locations**

P3 : A person can only be in **one location at a time**

D1 : **Outside** is a location where everybody can be

P4 : A person is always in some location

P5 : A person is always authorized to be in his location.



# Example

## Sets

persons = { p1, p2, p3 }  
locations = { l1, l2, l3, l4 }

## Authorizations

p1	l2, l4
p2	l1, l3, l4
p3	l2, l3, l4

## Correct scenario

p1	l4	→	p1	l2	→	p1	l2	→	p1	l4	→	p1	l4
p2	l4		p2	l4		p2	l1		p2	l1		p2	l1
p3	l4		p3	l4		p3	l4		p3	l4		p3	l3

# Model (1)

**Basic sets** : persons  $P$  and locations  $B$  (prop. P1)

**Constant** : authorizations  $A$  (prop. P2)

$A$  is a **binary relation** between  $P$  and  $B$

$$A \in P \leftrightarrow B$$

Constant : *outside* is a location where everybody is authorized to be (decision D1)

$outside \in \mathbb{B}$

$$P \times \{outside\} \subseteq A$$

## Model (3)

**Variable** : situations  $C$  (prop. P3 and P4)

$C$  is a **total function** between  $P$  and  $B$

A total function is a **special case** of a binary relation

$$C \in P \rightarrow B$$

**Invariant** : situations **compatible** with auth. (prop. P5)

The function  $C$  is **included** in the relation  $A$

$$C \subseteq A$$

# A magic event which can be observed

- GUARD :  $\left\{ \begin{array}{l} \text{- Given some person } p \text{ and location } l \\ \text{- } p \text{ is authorized to be in } l : p, l \in A \\ \text{- } p \text{ is not currently in } l : c(p) \neq l \end{array} \right.$
- ACTION :  $\text{- } p \text{ jumps into } l$

```
EVENT observation1  $\hat{=}$   
  ANY  $p, l$  WHERE  
     $p \in P \wedge$   
     $l \in B \wedge$   
     $p \mapsto l \in A \wedge$   
     $c(p) \neq l$   
  THEN  
     $c(p) := l$   
  END
```

Given two relations  $a$  and  $b$

Overriding  $a$  by  $b$  yields a new relation  $a \triangleleft b$

$$a \triangleleft b \quad \hat{=} \quad (\text{dom}(b) \triangleleft a) \cup b$$

Abbreviation

$$f(x) := y \quad \hat{=} \quad f := f \triangleleft \{x \mapsto y\}$$

INVARIANT  $\wedge$  GUARD  
 $\implies$   
ACTION establishes INVARIANT

$$\begin{aligned} & c \subseteq A \quad \wedge \\ & p \in P \quad \wedge \\ & l \in B \quad \wedge \\ & p \mapsto l \in A \\ \implies & (\{p\} \triangleleft c) \cup \{p \mapsto l\} \subseteq A \end{aligned}$$

P6 : The geometry define how locations **communicate**

P7 : A location does not communicate with itself

P8 : Persons move **between communicating locations**



**Constant** : communication STRUCTURE (prop. P6 and P7)  
STRUCTURE is a binary relation between B  
The intersection of STRUCTURE with the **identity relation** on B is empty

$$\text{STRUCTURE} \in B \leftrightarrow B$$

$$\text{STRUCTURE} \cap \text{id}(B) = \emptyset$$

# Correct Refinement Verification (reminder)

Concrete events **do not block more often than abstract ones**

$$\begin{array}{l} I(x) \wedge J(x, y) \wedge \\ \text{disjunction of abstract guards} \\ \implies \\ \text{disjunction of concrete guards} \end{array}$$

**New events block eventually** (decreasing the same quantity  $V(y)$ )

$$I(x) \wedge J(x, y) \wedge H(y) \wedge V(y) = n \implies V(F(y)) < n$$

Event (prop. P8)

The guard is **strengthened**

The current location of  $p$  and the new location  $l$  **must communicate**

```
EVENT observation1  $\hat{=}$   
  ANY  $p, l$  WHERE  
     $p \in P \wedge$   
     $l \in B \wedge$   
     $p \mapsto l \in A \wedge$   
     $c(p) \neq l$   
  THEN  
     $c(p) := l$   
  END
```

```
EVENT observation2  $\hat{=}$   
  REFINES observation1  
  ANY  $p, l$  WHERE  
     $p \in P \wedge$   
     $l \in B \wedge$   
     $p \mapsto l \in A \wedge$   
     $c(p) \mapsto l \in \text{STRUCTURE}$   
  THEN  
     $c(p) := l$   
  END
```

Invariant preservation : **Success**

Guard strengthening : **Success**

$$\begin{aligned} & \exists (p, l) \cdot (p \mapsto l \in A \wedge C(p) \mapsto l \in \text{STRUCTURE}) \\ \Rightarrow & \\ & \exists (p, l) \cdot (p \mapsto l \in A \wedge C(p) \neq l) \end{aligned}$$

Deadlockfreeness : **Failure**

$$\begin{aligned} & \exists (p, l) \cdot (p \mapsto l \in A \wedge C(p) \neq l) \\ \Rightarrow & \\ & \exists (p, l) \cdot (p \mapsto l \in A \wedge C(p) \mapsto l \in \text{STRUCTURE}) \end{aligned}$$

P9 : No person must remain blocked in a location.

**Solution**

P10 : Any person authorized to be in a location must also be authorized to go in another location which communicates with the first one.

$$A \subseteq A ; \text{STRUCTURE}^{-1}$$

$$p \mapsto l \in A \implies \exists m \cdot (p \mapsto m \in A \wedge l \mapsto m \in \text{STRUCTURE})$$

# Example

p1	l2	p2	l4
p1	l4	p3	l2
p2	l1	p3	l3
p2	l3	p3	l4

A

l1	l3
l1	l4
l3	l2
l4	l1
l4	l2
l4	l3

STRUCTURE

l1	l4
l2	l3
l2	l4
l3	l1
l3	l4
l4	l1

STRUCTURE<sup>-1</sup>

p1	l1	p
p1	l3	p
p1	l4	p
p2	l1	p

A; STRUCTURE

- Opening a door between l2 and l4
- Authorizing p2 to go to l2



p1	l2	p2	l4
p1	l4	p3	l2
p2	l1	p3	l3
p2	l2	p3	l4
p2	l3		

A

l1	l3
l1	l4
l2	l4
l3	l2
l4	l1
l4	l2
l4	l3

STRUCTURE

l1	l4
l2	l3
l2	l4
l3	l1
l3	l4
l4	l1
l4	l2

STRUCTURE<sup>-1</sup>

p1	l1	p2
p1	l2	p2
p1	l3	p3
p1	l4	p3
p2	l1	p3
p2	l2	p3

A; STRUCTURE

## Decision

D2 : The system that we are going to construct does not guarantee that people can move “outside”.



# A better solution (1)

Constante : *exit* is a function, included in *com*, with no cycle

$$exit \in B - \{outside\} \rightarrow B$$

$$exit \subseteq com$$

$$\forall s \cdot (s \subseteq B \implies (s \subseteq exit^{-1}[s] \implies s = \emptyset))$$

$$\begin{aligned} & \forall x \cdot (x \in s \implies \exists y \cdot (y \in s \wedge (x, y) \in exit)) \\ \implies \\ & s = \emptyset \end{aligned}$$

*exit* is a tree **spanning** the graph represented by *com*

## A better solution (2)

P10' : Every person authorized to be in a location (which is not “outside”) must also be authorized to be in another location communicating with the former and **leading towards the exit**.

$$A \triangleright \{outside\} \subseteq A ; exit^{-1}$$

$$\begin{aligned} p \mapsto l \in A \wedge \\ l \neq outside \\ \implies \\ p \mapsto exit(l) \in A \end{aligned}$$

Show that no cycle implies the possibility to prove property by **induction** and vice-versa

$$\forall s \cdot (s \subseteq B \wedge s \subseteq \text{exit}^{-1}[s] \implies s = \emptyset)$$

$\Leftrightarrow$

$$\forall t \cdot (t \subseteq B \wedge \text{outside} \in t \wedge \text{exit}^{-1}[t] \subseteq t \implies t = B)$$

$$t \subseteq B$$

$$\text{outside} \in t$$

$$\forall (x, y) \cdot ((x \mapsto y) \in \text{exit} \wedge y \in t \implies x \in t)$$

$\implies$

$$t = B$$

## Second Refinement : Introducing Doors

P11 : Locations communicate via one-way doors.

P12 : A person get through a door only if accepted.

P13 : A door is acceptable by at most one person at a time.

P14 : A person is accepted for at most one door only.

P15 : A person is accepted if at the origin of the door.

P16 : A person is accepted if authorized at destination.

# Extending the Model (1)

**Set** : the set DOORS of doors

**Constants** : The origin ORG and destination DST of a door  
(prop. P11)

$$\begin{aligned}\text{ORG} &\in \text{DOORS} \rightarrow \mathbf{B} \\ \text{DST} &\in \text{DOORS} \rightarrow \mathbf{B} \\ \text{STRUCTURE} &= (\text{ORG}^{-1} ; \text{DST})\end{aligned}$$

## Extending the Model (2)

**Variable** : the rel. DAP between persons and doors (prop. P12 to P16)

$$\begin{aligned} \text{DAP} &\in P \rightsquigarrow \text{DOORS} \\ (\text{DAP} ; \text{ORG}) &\subseteq C \\ (\text{DAP} ; \text{DST}) &\subseteq A \end{aligned}$$

## Second Refinement : More Properties

P17 : Green light of a door is lit when access is accepted.

P18 : When a person has got through, the door blocks.

P19 : After 30 seconds, the door blocks automatically.

P20 : Red light is lit for 2 sec. when access is refused.

P21 : Red and green lights are not lit simultaneously.

**Definition** : **GREEN** is exactly the range of DAP (prop. P17 to P19)

$$\text{GREEN} \hat{=} \text{ran}(\text{DAP})$$



## Extending the Model (4)

**Variable** : The set *red* of red doors (prop. P20)

$$red \subseteq \text{DOORS}$$

**Invariant** : **GREEN** and *red* are incompatible (prop. P21)

$$\text{GREEN} \cap red = \emptyset$$

P22 : Person  $p$  is accepted through door  $d$  if

- $p$  is situated within the origin of  $d$
- $p$  is authorized to move to the dest. of  $d$
- $p$  is not engaged with another door

$$\begin{aligned} \text{admitted}(p, d) \hat{=} & \\ & \text{ORG}(d) = c(p) \quad \wedge \\ & p \mapsto \text{DST}(d) \in A \quad \wedge \\ & p \notin \text{dom}(dap) \end{aligned}$$

# A New Event (1)

Accepting a person  $p$  - GUARD :

- $\left\{ \begin{array}{l} - \text{ Given some person } p \text{ and door } d \\ - d \text{ is neither green nor red} \\ - p \text{ is admissible through } d \end{array} \right.$
- ACTION : - make  $p$  authorized to pass  $d$

```
EVENT accept  $\hat{=}$   
  ANY  $p, d$  WHERE  
     $p \in P \wedge$   
     $d \in \text{DOORS} \wedge$   
     $d \notin \text{GREEN} \cup \text{red} \wedge$   
    admitted( $p, d$ )  
  THEN  
    DAP( $p$ ) :=  $d$   
  END
```

## A New Event (2)

Refusing a person  $p$

- GUARD :  $\left\{ \begin{array}{l} - \text{Given some person } p \text{ and door } d \\ - d \text{ is neither green nor red} \\ - p \text{ is not admissible through } d \end{array} \right.$
- ACTION :
  - lit the red light

```
EVENT refuse  $\hat{=}$   
  ANY  $p, d$  WHERE  
     $p \in P \wedge$   
     $d \in \text{DOORS} \wedge$   
     $d \notin \text{GREEN} \cup \text{red} \wedge$   
     $\neg \text{admitted}(p, d)$   
  THEN  
     $\text{red} := \text{red} \cup \{d\}$   
  END
```

# Refining Event OBSERVATION2

```
EVENT observation2  $\hat{=}$   
  ANY  $p, l$  WHERE  
     $p \in P$   
     $l \in B$   
     $p, l \in A$   
     $C(p) \mapsto l \in \text{STRUCTURE}$   
  THEN  
     $C(p) := l$   
  END
```

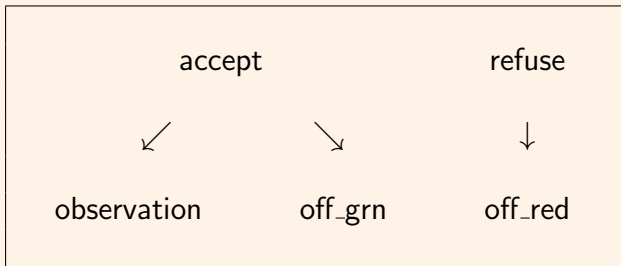
```
EVENT observation3  $\hat{=}$   
  REFINES observation2  
  ANY  $d$  WHERE  
     $d \in \text{GREEN}$   
  THEN  
     $C(\text{DAP}^{-1}(d)) := \text{DST}(d)$   
     $\text{DAP} := \text{DAP} \triangleright \{d\}$   
  END
```

## Turning lights off

```
EVENT off_grn  $\hat{=}$   
  ANY  $d$  WHERE  
     $d \in \text{GREEN}$   
  THEN  
    DAP := DAP  $\triangleright$  { $d$ }  
  END
```

```
EVENT off_red  $\hat{=}$   
  ANY  $d$  WHERE  
     $d \in \text{red}$   
  THEN  
     $\text{red} := \text{red} - \{d\}$   
  END
```

# Synchronization



- Event observation is a **correct refinement** : OK
- Other events **refine skip** : OK
- Event observation **does not deadlock more** : OK
- New events **do not take control indefinitely** : FAILURE





D3 : The system we are going to construct will not prevent people from **blocking doors indefinitely** :

- either by trying indefinitely to enter places into which they are **not authorized to enter**,
- or by indefinitely abandoning “on the way” their intention to enter the places in which they are in fact **authorized to enter**.

## A decision

D4 : Each card reader is supposed to stay blocked between :

- the **sending** of a card to the system
- the **reception** of an acknowledgement.

## Third Refinement : Model Extension

## The set $BLR$ of blocked Card Readers

The set  $mCard$  of messages sent by Card Readers

The set  $mAckn$  of acknowledgment messages

$$BLR \subset \text{DOORS}$$

$$mCard \in \text{DOORS} \rightarrow \text{P}$$

$mAckn \subset \text{DOORS}$

# Third Refinement : Invariant

$\text{dom}(mCard), \text{GREEN}, red, mAckn \text{ partition } BLR$

$$\text{dom}(mCard) \cup \text{GREEN} \cup red \cup mAckn = BLR$$

$$\text{dom}(mCard) \cap (\text{GREEN} \cup red \cup mAckn) = \emptyset$$

$$mAckn \cap (\text{GREEN} \cup red) = \emptyset$$

## Events (1)

```

EVENT CARD  $\hat{=}$ 
  ANY  $p, d$ 
  WHERE
     $p \in P$ 
     $d \in \text{DOORS} - BLR$ 
  THEN
     $BLR := BLR \cup \{d\}$ 
     $mCard := mCard \cup \{d \mapsto p\}$ 
  END

```

## Events (2)

```
EVENT accept3  $\hat{=}$   
  ANY  $p, d$   
  WHERE  
     $p \in P$   
     $d \in \text{DOORS}$   
     $d \notin \text{green} \cup \text{red}$   
    admitted( $p, d$ )  
  THEN  
    DAP( $p$ ) :=  $d$   
  END
```

```
EVENT accept4  $\hat{=}$   
  REFINES accept3  
  ANY  $p, d$   
  WHERE  
     $d \mapsto p \in mCard$   
    admitted( $p, d$ )  
  THEN  
    DAP( $p$ ) :=  $d$   
     $mCard := mCard - \{d \mapsto p\}$   
  END
```

# Events (3)

```
EVENT refuse4  $\hat{=}$   
  REFINES refuse3  
  ANY  $p, d$   
  WHERE  
     $d \mapsto p \in mCard$   
     $\neg \text{admitted}(p, d)$   
  THEN  
     $red := red \cup \{d\}$   
     $mCard := mCard - \{d \mapsto p\}$   
  END
```



## Events (4)

```

EVENT observation4  $\hat{=}$ 
  REFINES observation3
  ANY  $d$ 
  WHERE
     $d \in \text{GREEN}$ 
  THEN
     $C(\text{DAP}^{-1}(d)) := \text{DST}(d)$ 
     $\text{DAP} := \text{DAP} \triangleright \{d\}$ 
     $mAckn := mAckn \cup \{d\}$ 
  END

```

# Events (5)

```
EVENT off_grn  $\hat{=}$   
  ANY  $d$  WHERE  
     $d \in \text{GREEN}$   
  THEN  
    DAP := DAP  $\triangleright$   $\{d\}$   
    mAckn := mAckn  $\cup$   $\{d\}$   
  END
```

```
EVENT off_red  $\hat{=}$   
  ANY  $d$  WHERE  
     $d \in \text{red}$   
  THEN  
    red := red -  $\{d\}$   
    mAckn := mAckn  $\cup$   $\{d\}$   
  END
```

## Events (6)

```

EVENT ACKN  $\triangleq$ 
  ANY  $d$  WHERE
     $d \in mAckn$ 
  THEN
     $BLR := BLR - \{d\}$ 
     $mAckn := mAckn - \{d\}$ 
  END

```

# Synchronization



## Decisions

D5 : When a door has been cleared, it **blocks itself** automatically **without any intervention** from the control system.

D6 : Each door incorporates a **local clock** for

- the extinction of the **green light after 30 sec.**
- the extinction of the **red light after 2 sec.**

## Extending the Model : the Green Chain (1)

The set  $mAccept$  of acceptance messages (to doors)

The set  $GRN$  of physical green doors

The set  $mPass$  of passing messages (from doors)

The set *mOff\_grn* of messages (from doors)

$$mAccept \subseteq \text{DOORS}$$

$GRN \subset \text{DOORS}$

$$mPass \subset \text{DOORS}$$

$$mOff\_grn \subseteq \text{DOORS}$$

## Extending the Model : the Green Chain (2)

$mAccept, GRN, mPass, mOff\_grn$  **partition**  $grn$

$$mAccept \cup GRN \cup mPass \cup mOff\_grn = grn$$

$$mAccept \cap (GRN \cup mPass \cup mOff\_grn) = \emptyset$$

$$GRN \cap (mPass \cup mOff\_grn) = \emptyset$$

$$mPass \cap mOff\_grn = \emptyset$$

# Extending the Model : the Red Chain (1)

The set *mRefuse* of messages (to doors)

The set *RED* of physical red doors

The set *mOff\_red* of messages (from doors)

$$mRefuse \subseteq \text{DOORS}$$

$$RED \subseteq \text{DOORS}$$

$$mOff\_red \subseteq \text{DOORS}$$



## Extending the Model : the Red Chain (2)

$mRefuse$ ,  $RED$ ,  $mOff\_red$  partition  $red$

$$mRefuse \cup RED \cup mOff\_red = red$$

$$mRefuse \cap (RED \cup mOff\_red) = \emptyset$$

$$RED \cap mOff\_red = \emptyset$$

# Events (1)

```
EVENT accept  $\hat{=}$   
  ANY  $p, d$  WHERE  
     $d, p \in mCard \wedge$   
    admitted( $p, d$ )  
  THEN  
    DAP( $p$ ) :=  $d$   
     $mCard := mCard - \{d \mapsto p\}$   
     $mAccept := mAccept \cup \{d\}$   
  END
```

## Events (2)

```
EVENT ACCEPT  $\hat{=}$   
  ANY  $d$  WHERE  
     $d \in mAccept$   
  THEN  
     $GRN := GRN \cup \{d\}$   
     $mAccept := mAccept - \{d\}$   
  END
```

## Events (3)

```

EVENT PASS  $\hat{=}$ 
  ANY  $d$  WHERE
     $d \in GRN$ 
  THEN
     $GRN := GRN - \{d\}$ 
     $mPass := mPass \cup \{d\}$ 
  END

```

## Events (4)

```
EVENT observation5  $\hat{=}$   
  REFINES observation4 ANY  $d$  WHERE  
     $d \in mPass$   
  THEN  
     $C(DAP^{-1}(d)) := DST(d)$   
     $DAP := DAP \triangleright \{d\}$   
     $mAckn := mAckn \cup \{d\}$   
     $mPass := mPass - \{d\}$   
  END
```

# Events (5)

```
EVENT OFF_GRN  $\hat{=}$   
  ANY  $d$  WHERE  
     $d \in GRN$   
  THEN  
     $GRN := GRN - \{d\}$   
     $mOff\_grn := mOff\_grn \cup \{d\}$   
  END
```

## Events (6)

```
EVENT off_grn  $\hat{=}$   
  ANY  $d$  WHERE  
     $d \in mOff\_grn$   
  THEN  
    DAP := DAP  $\triangleright \{d\}$   
     $mAckn := mAckn \cup \{d\}$   
     $mOff\_grn := mOff\_grn - \{d\}$   
  END
```

# Events (7)

```
EVENT refuse  $\hat{=}$   
  ANY  $p, d$  WHERE  
     $d, p \in mCard \wedge$   
     $\neg \text{admitted}(p, d)$   
  THEN  
     $red := red \cup \{d\}$   
     $mCard := mCard - \{d \mapsto p\}$   
     $mRefuse := mRefuse \cup \{d\}$   
  END
```



## Events (8)

```
EVENT REFUSE  $\hat{=}$   
  ANY  $d$  WHERE  
     $d \in mRefuse$   
  THEN  
     $RED := RED \cup \{d\}$   
     $mRefuse := mRefuse - \{d\}$   
  END
```

## Events (9)

```

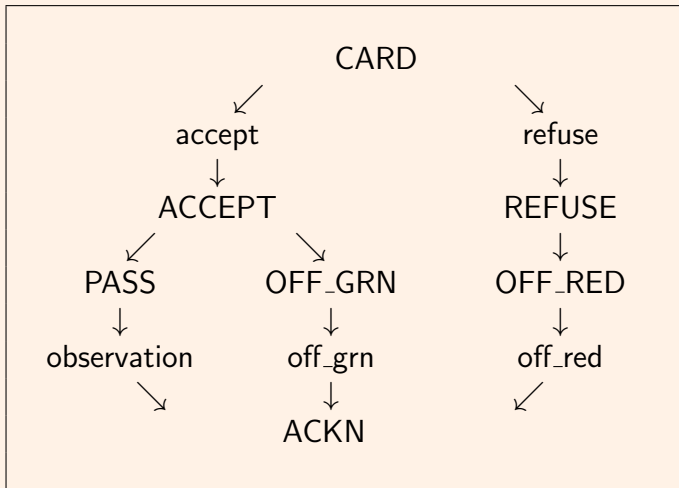
EVENT OFF_RED  $\triangleq$ 
  ANY  $d$  WHERE
     $d \in RED$ 
  THEN
     $RED := RED - \{d\}$ 
     $mOff\_red := mOff\_red \cup \{d\}$ 
  END

```

# Events (10)

```
EVENT off_red  $\hat{=}$   
  ANY  $d$  WHERE  
     $d \in mOff\_red$   
  THEN  
     $red := red - \{d\}$   
     $mAckn := mAckn \cup \{d\}$   
     $mOff\_red := mOff\_red - \{d\}$   
  END
```

# Synchronization



Hardware	Network			Software
CARD	→	<i>mCard</i>	→	{ accept (1) refuse (2)
ACCEPT	←	<i>mAccept</i>	←	(1)
PASS	→	<i>mPass</i>	→	observation (3)
OFF_GRN	→	<i>mOff_grn</i>	→	off_grn (3)
REFUSE	←	<i>mRefuse</i>	←	(2)
OFF_RED	→	<i>mOff_red</i>	→	off_red (3)
ACKN	←	<i>mAckn</i>	←	(3)

## Software Data

$$\begin{aligned} aut &\in P \leftrightarrow B \\ \text{ORG} &\in \text{DOORS} \rightarrow B \\ \text{DST} &\in \text{DOORS} \rightarrow B \\ A &\subseteq A; \text{DST}^{-1}; \text{ORG} \\ C &\in P \rightarrow B \end{aligned}$$
$$\begin{aligned} dap &\in P \rightsquigarrow \text{DOORS} \\ red &\subseteq \text{DOORS} \end{aligned}$$

## Decomposition (2)

## Network data

$$mCard \in \text{DOORS} \rightarrow P$$

$$mAckn \subseteq \text{DOORS}$$

$$mAccept \subseteq \text{DOORS}$$

$$mPass \subseteq \text{DOORS}$$

$$mOff\_grn \subseteq \text{DOORS}$$

$$mRefuse \subseteq \text{DOORS}$$

$$mOff\_red \subseteq \text{DOORS}$$

## “Physical” Data

$$BLR \subseteq \text{DOORS}$$

$$GRN \subseteq \text{DOORS}$$

$RED \subseteq \text{DOORS}$



EVENT test\_soft( $p, d$ )

EVENT accept\_soft( $p, d$ )

EVENT  $\text{refuse\_soft}(d)$

EVENT pass\_soft( $d$ )

EVENT off\_grn\_soft( $d$ )

EVENT off\_red\_soft( $d$ )

$$(p, d) \leftarrow \text{CARD\_HARD}$$
$$\text{ACCEPT\_HARD}(d)$$
$$\text{REFUSE\_HARD}(d)$$
$$d \leftarrow \text{PASS\_HARD}$$
$$d \leftarrow \text{OFF\_GRN\_HARD}$$
$$d \leftarrow \text{OFF\_RED\_HARD}$$
$$\text{ACKN\_HARD}(d)$$

# Network Software Operations

$$(p, d) \leftarrow \text{read\_card}$$

```
write_accept( $d$ )
```

write\_refuse( $d$ )

$$d \leftarrow \text{read\_pass}$$
$$d \leftarrow \text{read\_off\_grn}$$
$$d \leftarrow \text{read\_off\_red}$$

```
write_ackn( $d$ )
```

# Network Physical Operations

$$\text{SEND\_CARD}(p, d)$$
$$d \leftarrow \text{RCV\_ACCEPT}$$
$$d \leftarrow \text{RCV\_REFUSE}$$
$$\text{SEND\_PASS}(d)$$
$$\text{SEND\_OFF\_GRN}(d)$$
$$\text{SEND\_OFF\_RED}(d)$$
$$d \leftarrow \text{RCV\_ACKN}$$

```
EVENT CARD  $\hat{=}$   
  VAR  $p, d$  IN  
     $(p, d) \leftarrow \text{READ\_HARD};$   
    SEND_CARD( $p, d$ )  
  END
```

```
EVENT accept_refuse  $\hat{=}$   
  VAR  $p, d, b$  IN  
     $(p, d) \leftarrow \text{read\_card};$   
     $b \leftarrow \text{EVENT test\_soft}(p, d);$   
    IF  $b = \text{true}$  THEN EVENT accept_soft( $p, d$ ); write_accept( $d$ )  
    ELSE EVENT refuse_soft( $d$ ); write_refuse( $d$ ) END  
  END
```

```
EVENT ACCEPT  $\hat{=}$   
  VAR  $d$  IN  
     $d \leftarrow \text{RCV\_ACCEPT};$   
    ACCEPT_HARD( $d$ )  
  END
```

```
EVENT REFUSE  $\hat{=}$   
  VAR  $d$  IN  
     $d \leftarrow \text{RCV\_REFUSE};$   
    REFUSE_HARD( $q$ )  
  END
```



## 22 Properties et 6 “System” Decisions - One Problem Generalization

- Access between locations
- One Negative Choice :
- Possible Card Readers Obstructions
- Three Physical Decisions
- Automatic Blocking of Doors
- Automatic Blocking of Card Readers
- Setting up of Clocks on Doors
- The overall development required 183 proofs
- 147 automatic (80%)
- 36 interactive

## Current Summary

- 1 Refinement of models
- 2 Summary on Event-B
- 3 The Access Control
- 4 Conclusion



## Conclusion

- Identify an abstract model
- Identify constants and states
- Identify components
- Plan the refinement
- Start as long as the model is not well defined !