Synchronous programming

Critical Real Time Embedded Software

David Lesens

Wednesday, 06 October 2010

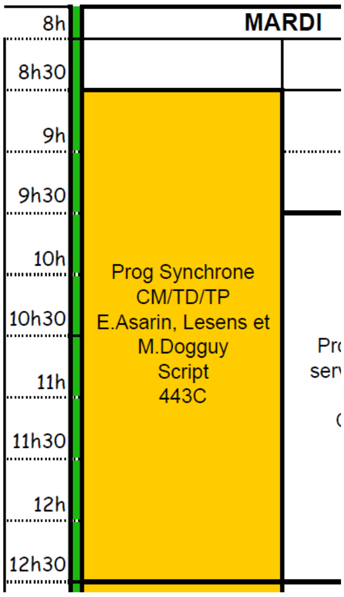
Synchronous programming

- Eugene Asarin
- Mehdi Dogguy

université PARIS DIDEROT PARIS 7

- David Lesens

ASTRIUM AN EADS COMPANY



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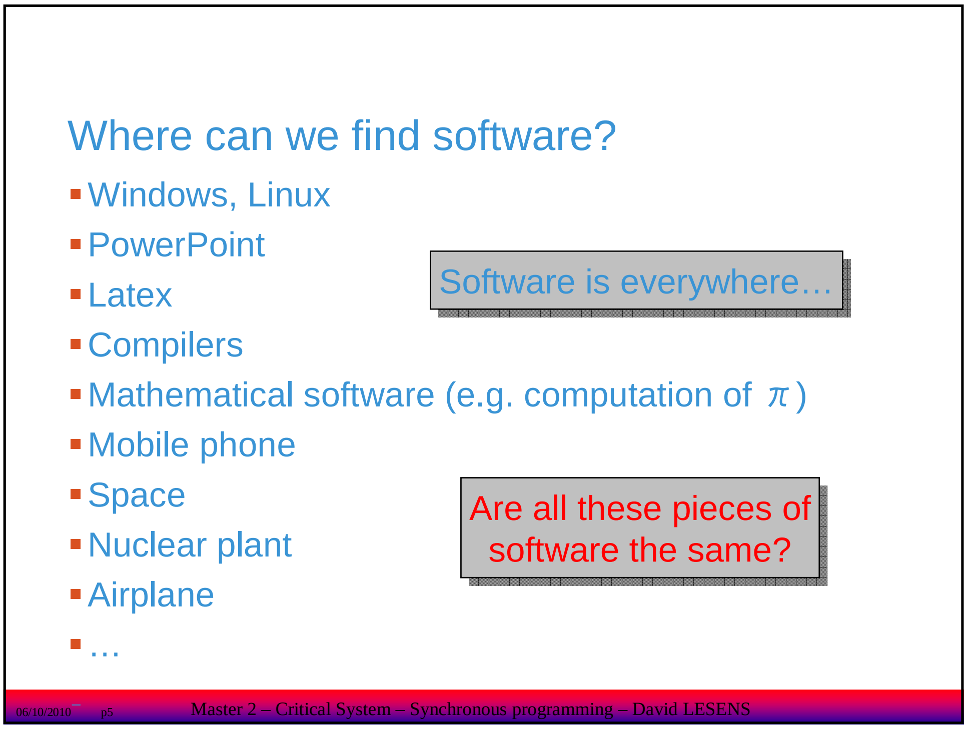
9h	Prog Synchrone CM/TD/TP E.Asarin, Lesens et M.Dogguy Script 443C	
9h30		
10h		
10h30		Pro ser (
11h		
11h30		
12h		
12h30		

Overview

- Critical real-time embedded software ☞
- Principles of the approach ☞
  - Introduction ☞
  - Formal semantics ☞
- SCADE ☞
- Model validation ☞

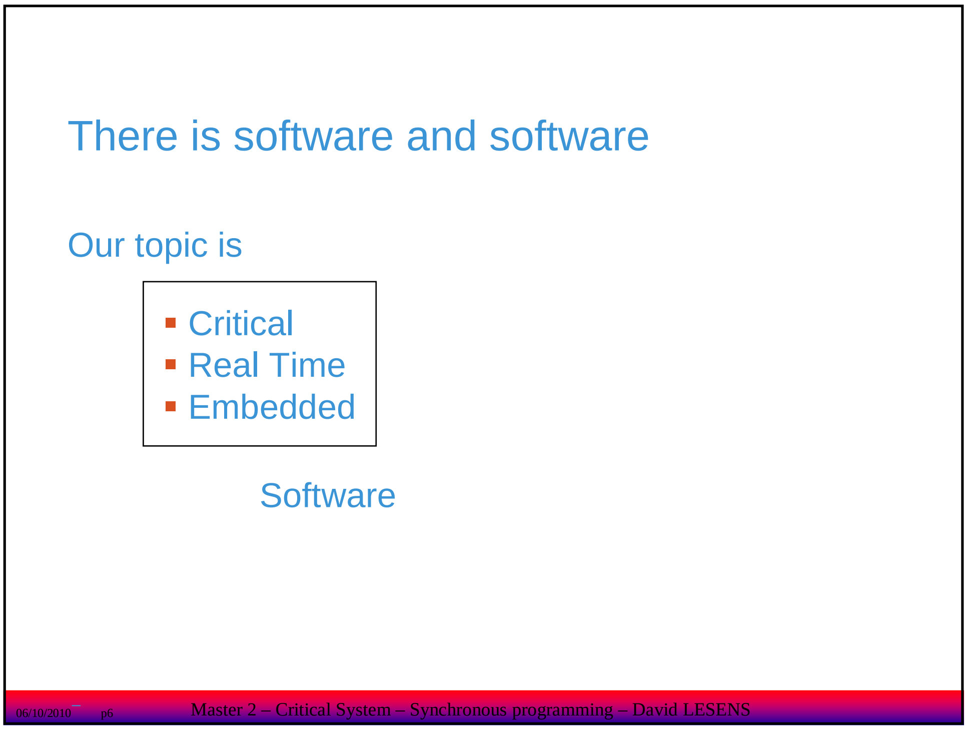


Where can we find software?

- Windows, Linux
- PowerPoint
- Latex
- Compilers
- Mathematical software (e.g. computation of π)
- Mobile phone
- Space
- Nuclear plant
- Airplane
- …

Software is everywhere…

Are all these pieces of software the same?



There is software and software

Our topic is

- Critical
- Real Time
- Embedded

Software

What is embedded software?

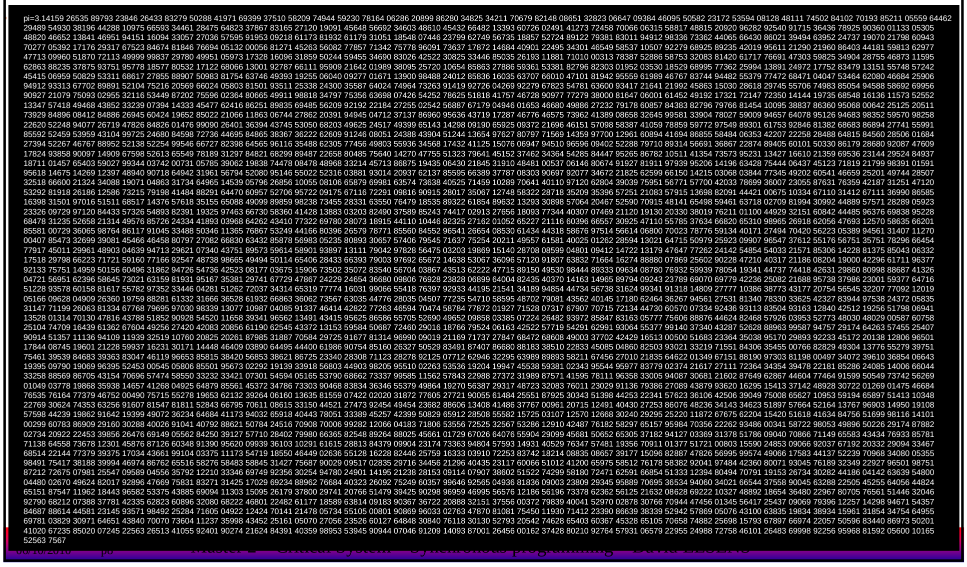
- Windows, Linux
- PowerPoint
- Latex
- Compilers
- Mathematical software (e.g. computation of π)

The software has its own objective
We can “buy” the software

- Mobile phone
- Space launcher
- Nuclear plant
- Airplane

The software is part of the system
We can only “buy” the system

Compute the first 10,000 digits of Pi



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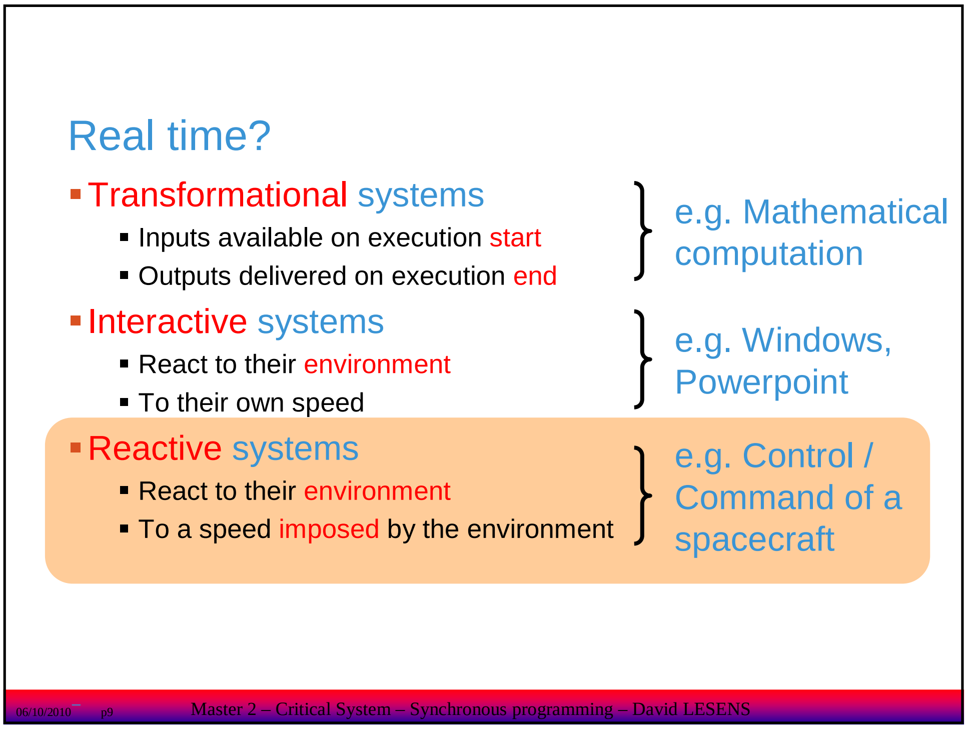


Real time?

- Transformational systems
  - Inputs available on execution start
  - Outputs delivered on execution end

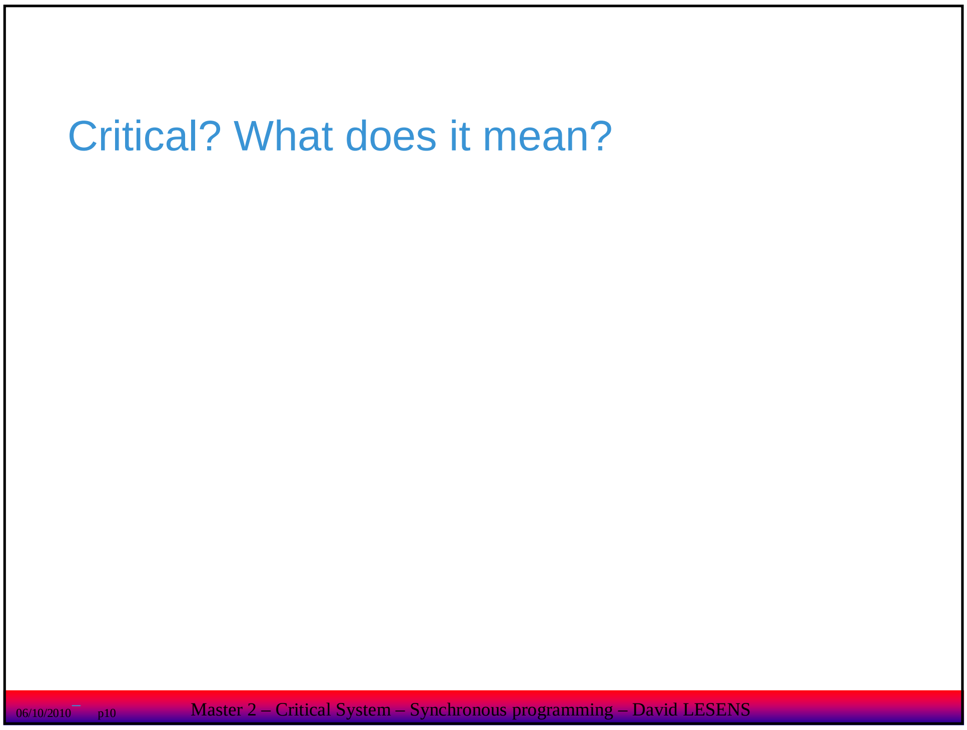
e.g. Mathematical computation

- Interactive systems
  - React to their environment
  - To their own speed

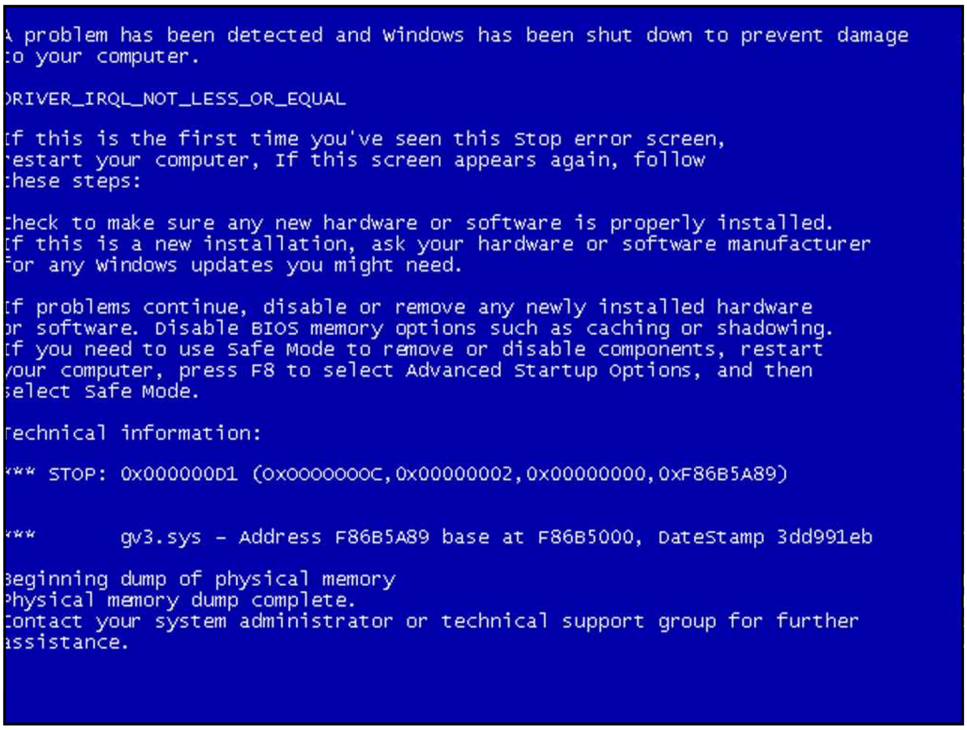
e.g. Windows, Powerpoint

- Reactive systems
  - React to their environment
  - To a speed imposed by the environment

e.g. Control / Command of a spacecraft



Critical? What does it mean?

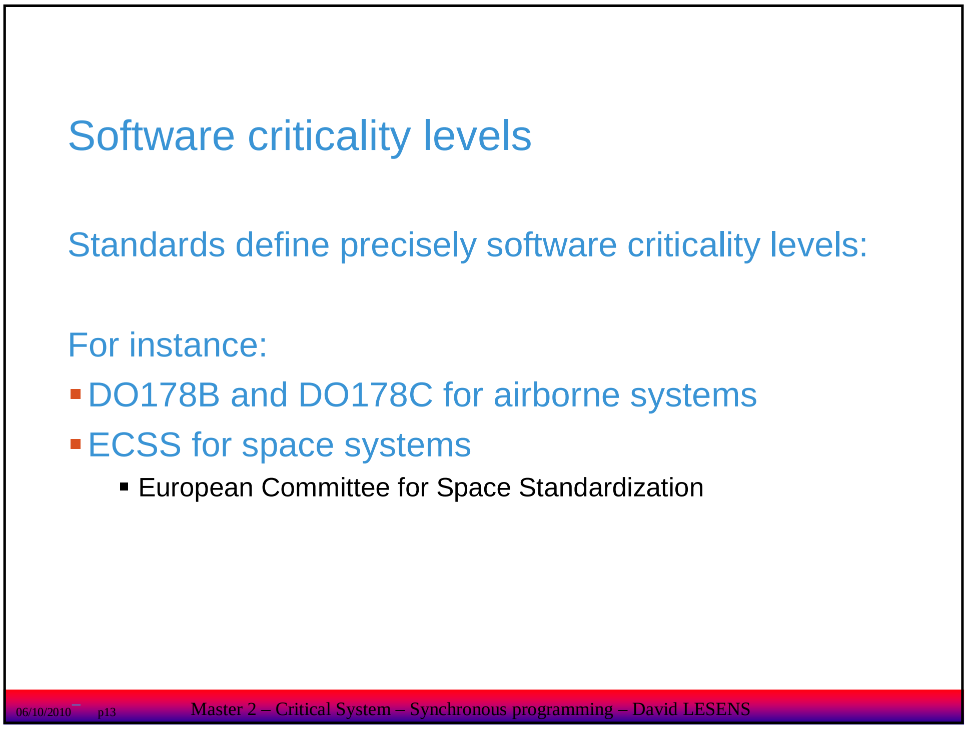


```
A problem has been detected and Windows has been shut down to prevent damage
to your computer.

DRIVER_IRQL_NOT_LESS_OR_EQUAL

If this is the first time you've seen this Stop error screen,
restart your computer. If this screen appears again, follow
these steps:

Check to make sure any new hardware or software is properly installed.
If this is a new installation, ask your hardware or software manufacturer
for any Windows updates you might need.

If problems continue, disable or remove any newly installed hardware
or software. Disable BIOS memory options such as caching or shadowing.
If you need to use Safe Mode to remove or disable components, restart
your computer, press F8 to select Advanced Startup Options, and then
select Safe Mode.

Technical information:

*** STOP: 0x000000D1 (0x0000000C,0x00000002,0x00000000,0xF86B5A89)


***       gv3.sys - Address F86B5A89 base at F86B5000, DateStamp 3dd991eb

Beginning dump of physical memory
Physical memory dump complete.
Contact your system administrator or technical support group for further
assistance.
```

Critical? What does it mean?

Intuitively, a critical system is a system which failure can have severe impacts

- Nuclear
- Aeronautic
- Automotive
- Railway
- Space
- …

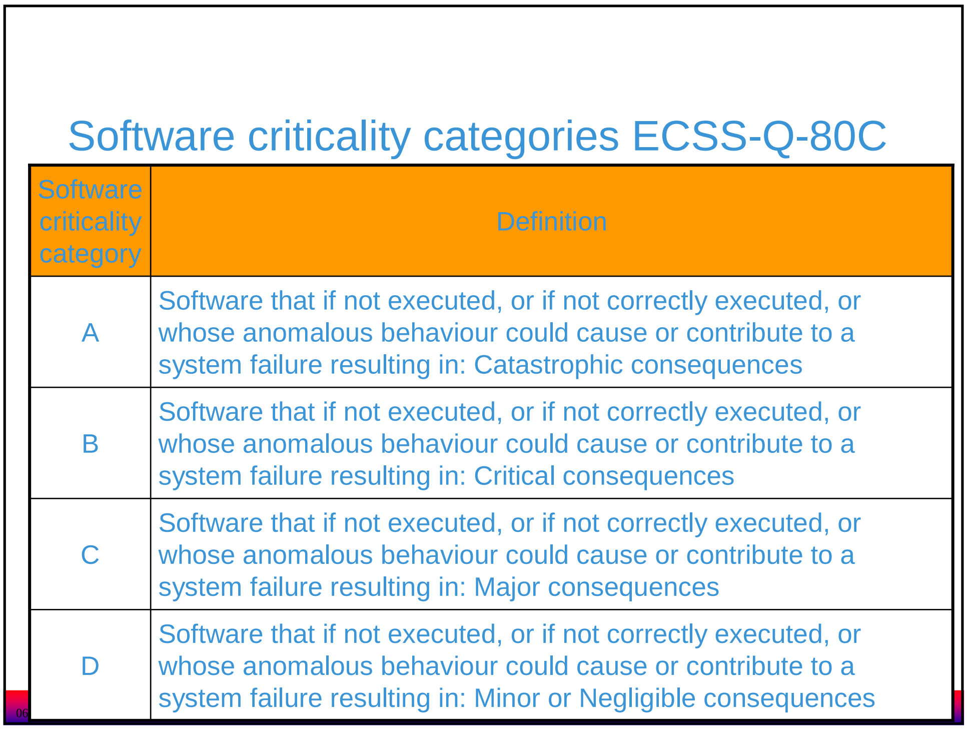


Software criticality levels

Standards define precisely software criticality levels:

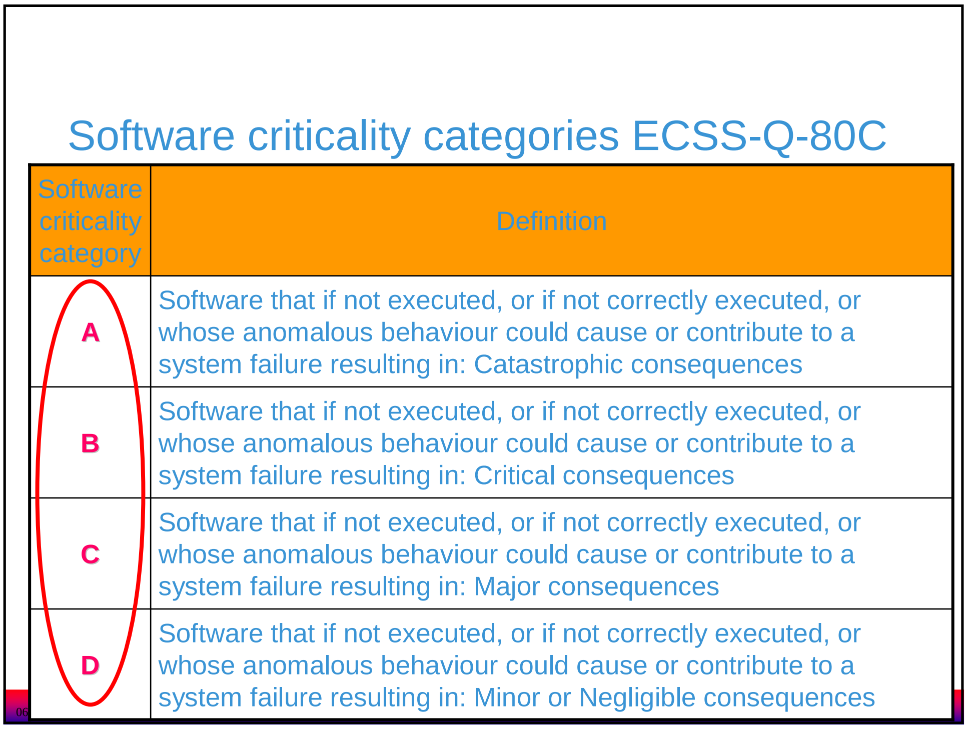
For instance:

- DO178B and DO178C for airborne systems
- ECSS for space systems
  - European Committee for Space Standardization



Software criticality categories ECSS-Q-80C

Software criticality category	Definition
A	Software that if not executed, or if not correctly executed, or whose anomalous behaviour could cause or contribute to a system failure resulting in: Catastrophic consequences
B	Software that if not executed, or if not correctly executed, or whose anomalous behaviour could cause or contribute to a system failure resulting in: Critical consequences
C	Software that if not executed, or if not correctly executed, or whose anomalous behaviour could cause or contribute to a system failure resulting in: Major consequences
D	Software that if not executed, or if not correctly executed, or whose anomalous behaviour could cause or contribute to a system failure resulting in: Minor or Negligible consequences



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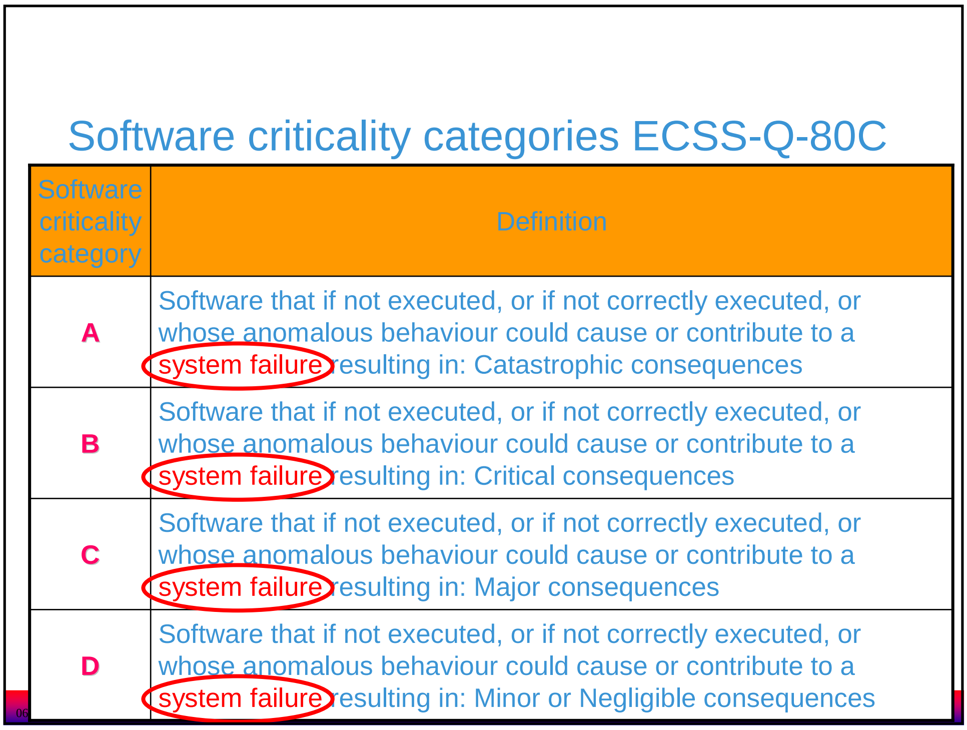

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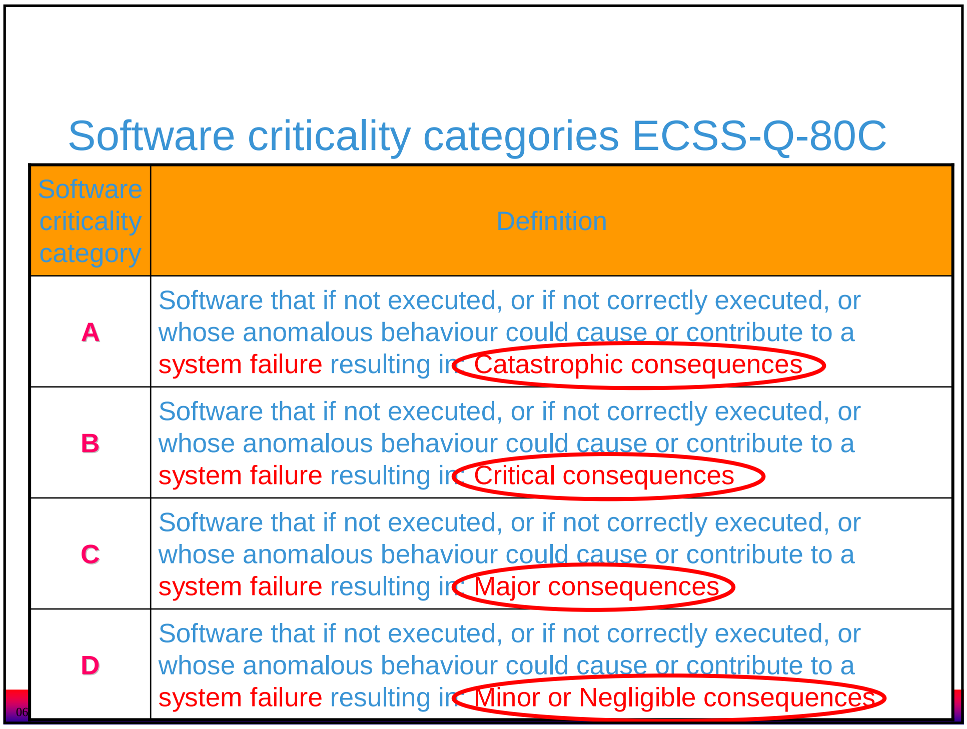

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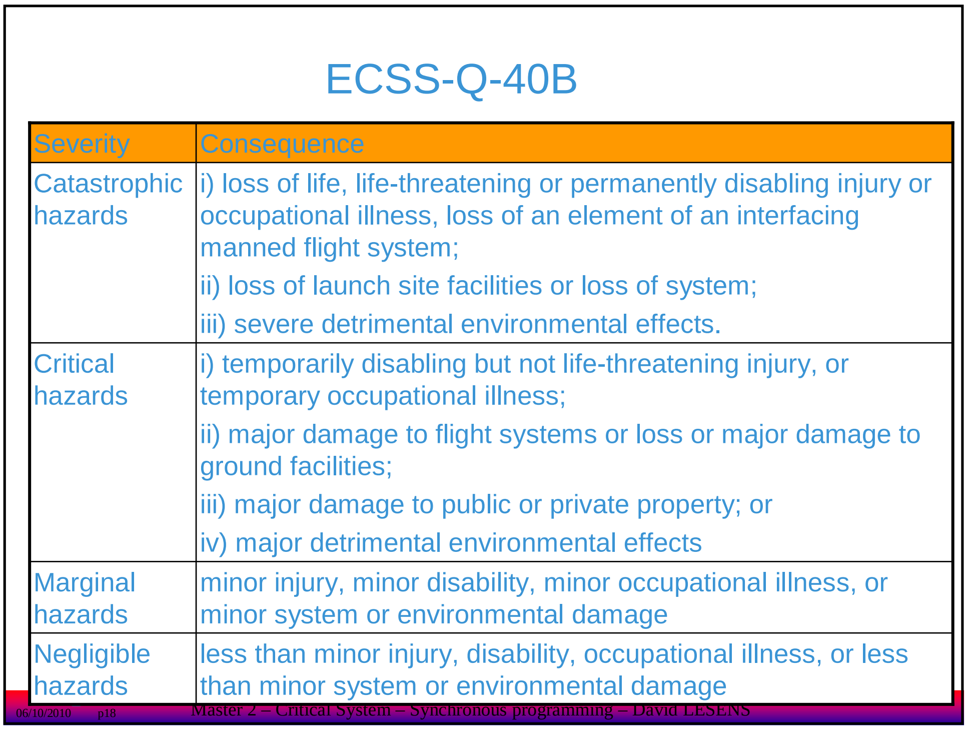
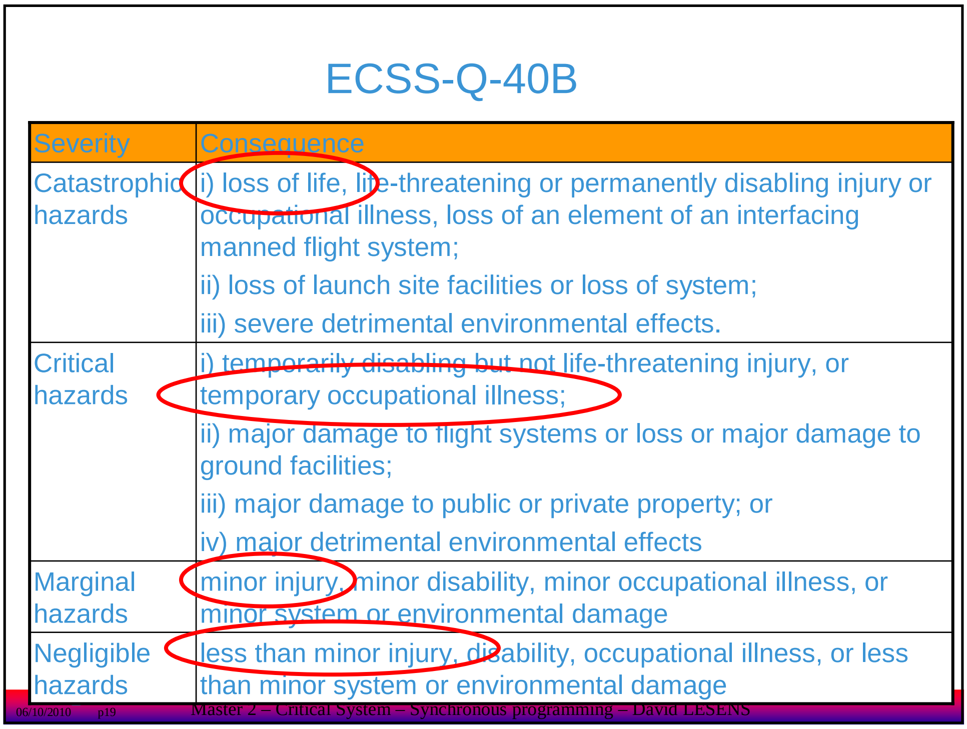


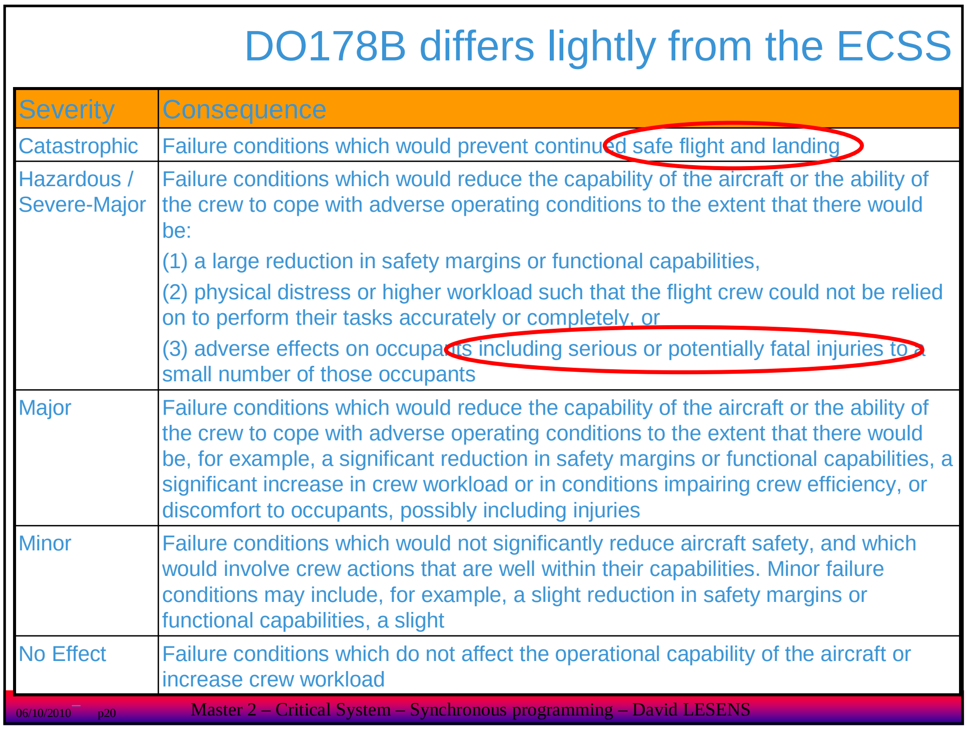
ECSS-Q-40B

Severity	Consequence
Catastrophic hazards	i) loss of life, life-threatening or permanently disabling injury or occupational illness, loss of an element of an interfacing manned flight system; ii) loss of launch site facilities or loss of system; iii) severe detrimental environmental effects.
Critical hazards	i) temporarily disabling but not life-threatening injury, or temporary occupational illness; ii) major damage to flight systems or loss or major damage to ground facilities; iii) major damage to public or private property; or iv) major detrimental environmental effects
Marginal hazards	minor injury, minor disability, minor occupational illness, or minor system or environmental damage
Negligible hazards	less than minor injury, disability, occupational illness, or less than minor system or environmental damage



ECSS-Q-40B

Severity	Consequence
Catastrophic hazards	i) loss of life, life-threatening or permanently disabling injury or occupational illness, loss of an element of an interfacing manned flight system; ii) loss of launch site facilities or loss of system; iii) severe detrimental environmental effects.
Critical hazards	i) temporarily disabling but not life-threatening injury, or temporary occupational illness; ii) major damage to flight systems or loss or major damage to ground facilities; iii) major damage to public or private property; or iv) major detrimental environmental effects
Marginal hazards	minor injury, minor disability, minor occupational illness, or minor system or environmental damage
Negligible hazards	less than minor injury, disability, occupational illness, or less than minor system or environmental damage



DO178B differs lightly from the ECSS

Severity	Consequence
Catastrophic	Failure conditions which would prevent continued safe flight and landing
Hazardous / Severe-Major	Failure conditions which would reduce the capability of the aircraft or the ability of the crew to cope with adverse operating conditions to the extent that there would be: (1) a large reduction in safety margins or functional capabilities, (2) physical distress or higher workload such that the flight crew could not be relied on to perform their tasks accurately or completely, or (3) adverse effects on occupants including serious or potentially fatal injuries to a small number of those occupants
Major	Failure conditions which would reduce the capability of the aircraft or the ability of the crew to cope with adverse operating conditions to the extent that there would be, for example, a significant reduction in safety margins or functional capabilities, a significant increase in crew workload or in conditions impairing crew efficiency, or discomfort to occupants, possibly including injuries
Minor	Failure conditions which would not significantly reduce aircraft safety, and which would involve crew actions that are well within their capabilities. Minor failure conditions may include, for example, a slight reduction in safety margins or functional capabilities, a slight
No Effect	Failure conditions which do not affect the operational capability of the aircraft or increase crew workload

Wikipedia

Vocabulary

- Security
  - is the degree of protection against danger, loss, and criminals.
- Reliability
  - is the ability of a person or system to perform and maintain its functions in routine circumstances, as well as hostile or unexpected circumstances.
- Safety
  - is the state of being "safe" (from French sauf), the condition of being protected against […] consequences of failure, damage, error, accidents, harm or any other event which could be considered non-desirable. It can include protection of people or of possessions.

Wikipedia

Safety & Security in Software Engineering

- The key difference between security and reliability is that security must take into account the actions of people attempting to cause destruction.

Safety

- The software must not harm the world

Security

- The world must not harm the software

Example 1: The First “Computer Bug”

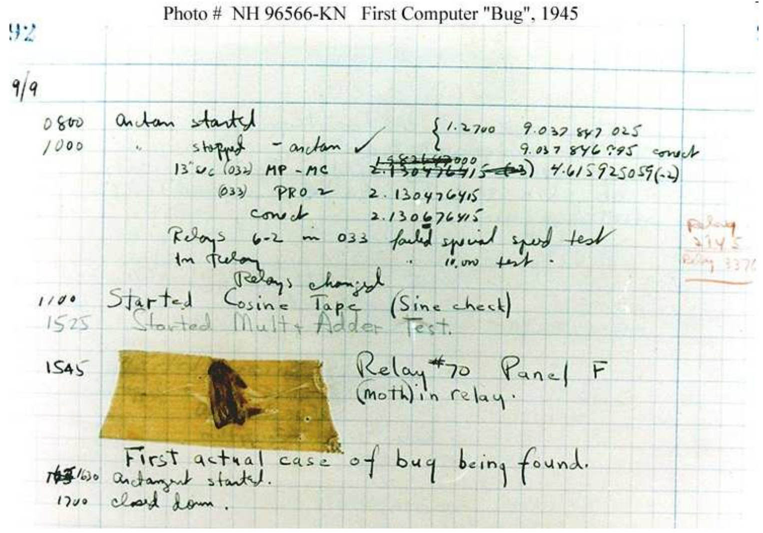


Photo # NH 96566-KN First Computer "Bug", 1945

92

9/9

0800 Anctan started

1000 " stopped - anctan ✓ {1.2700 9.037 847 025

9.037 846 795 correct

13" uc (032) MP - MC ~~1.982147000~~ ~~2.130476415~~ ~~(-3)~~ 4.615925059(-2)

(033) PRO 2 2.130476415

correct 2.130676415

Relays 6-2 in 033 failed special speed test

in relay " 11,000 test .

Relays changed

1100 Started Cosine Tape (Sine check)

1525 Started Mult + Adder Test.

1545 Relay #70 Panel F

(moth) in relay.

First actual case of bug being found.

~~1630~~ 1630 Antangent started.

1700 closed down.

Relay 2145

Relay 3370

Example 2: The Patriot Missile Failure

On February 25, 1991, during the Gulf War, an American Patriot Missile battery in Dharan, Saudi Arabia, failed to track and intercept an incoming Iraqi Scud missile. The Scud struck an American Army barracks, killing 28 soldiers and injuring around 100 other people. A report of the General Accounting office, GAO/IMTEC-92-26, entitled *Patriot Missile Defense: Software Problem Led to System Failure at Dhahran, Saudi Arabia* reported on the cause of the failure. It turns out that the cause was an inaccurate calculation of the time since boot due to computer arithmetic errors.

Failure in space

Trident

Sea launch

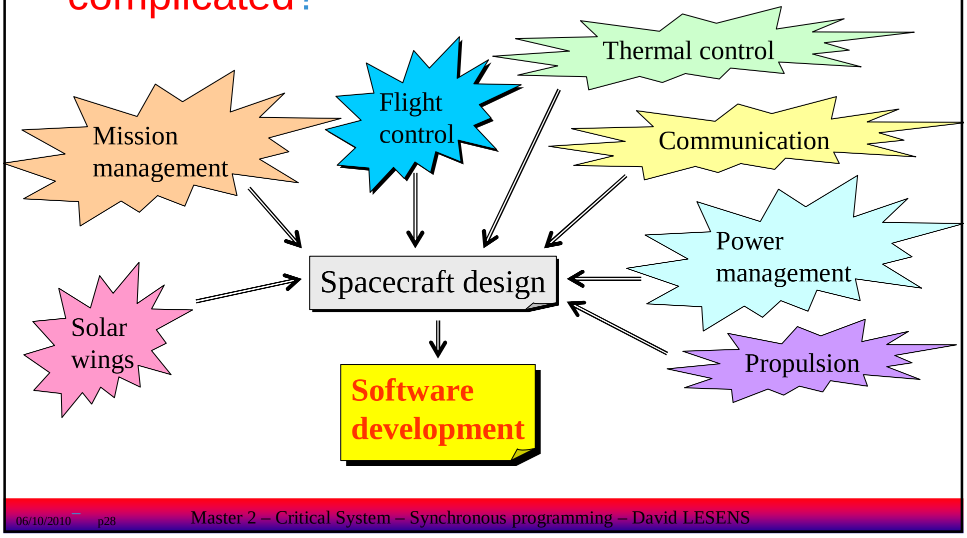
Overview

- Critical real-time embedded software ☞
- Principles of the approach ☞
  - Introduction ☞
  - Formal semantics ☞
- SCADE ☞
- Model validation ☞

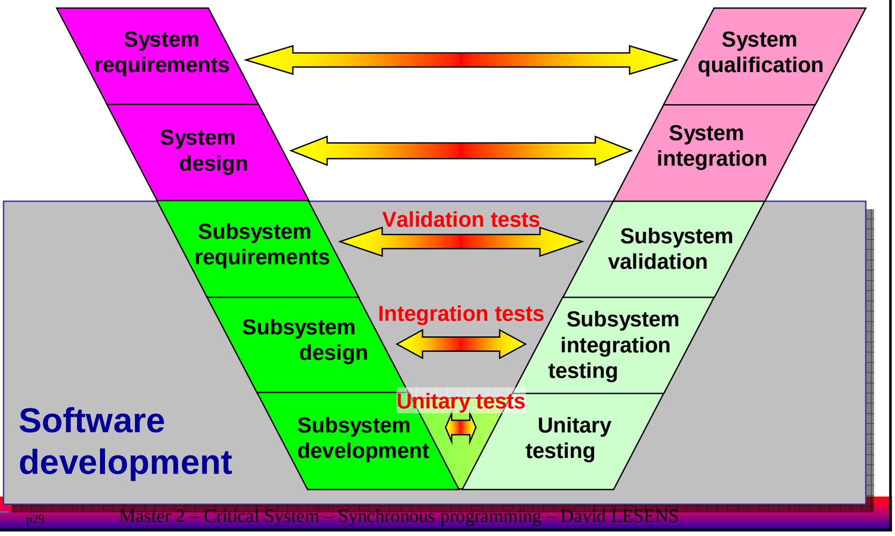
NASA's Climate Orbiter was lost September 23, 1999, due to a software bug

One engineering team used metric units while another used English units

Why is System (to Software) Engineering complicated?



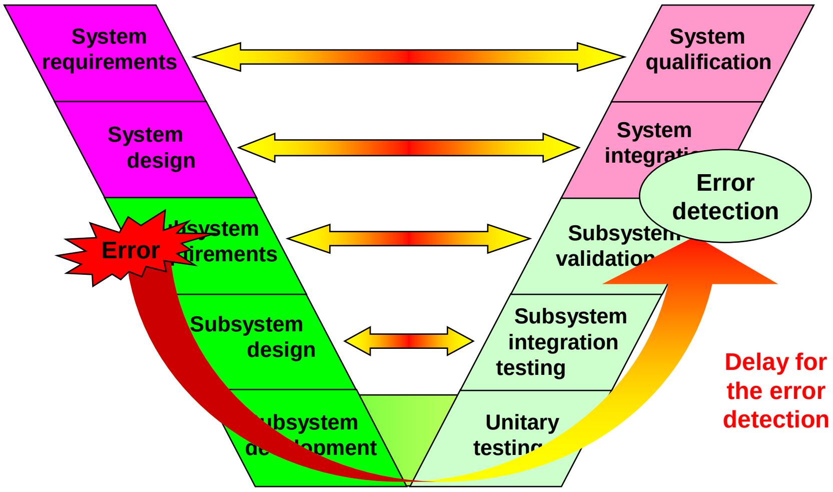
The V development cycle



Costs of critical software development

Specification	10%
Design	10%
Development/TU	25%
Integration tests	5%
Validation	**50%**

Late detection of errors



System requirements

System design

Subsystem requirements

Subsystem design

Subsystem development

System qualification

System integration

Subsystem validation

Subsystem integration testing

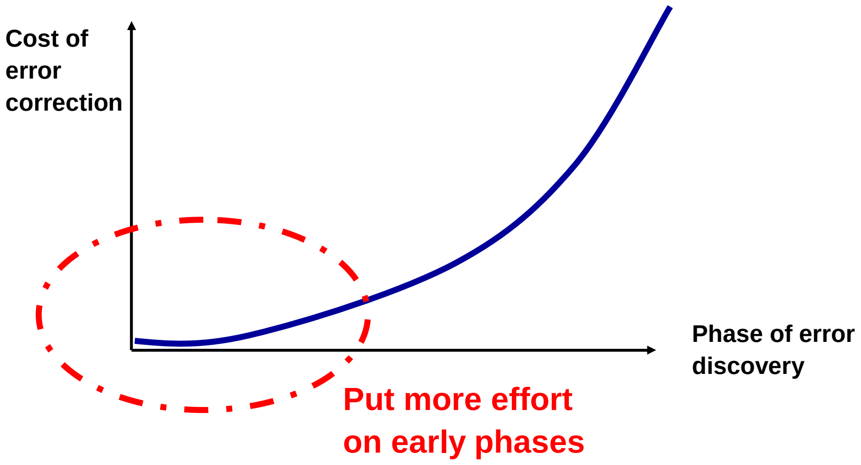
Unitary testing

Error

Error detection

Delay for the error detection

Cost of error correction

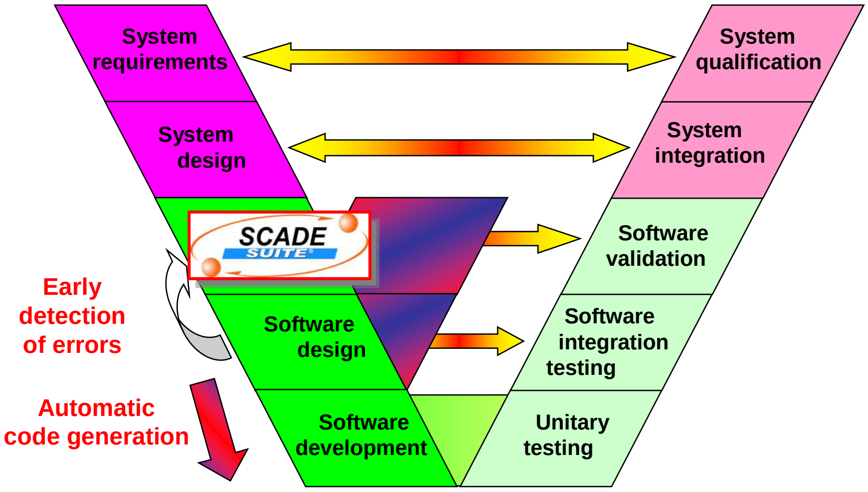


Cost of error correction

Phase of error discovery

Put more effort on early phases

Verification with model driven engineering



Formal Model Driven Engineering shall allow

- An early verification of the specification via a strong and intuitive semantic ensuring
  - Consistency
  - Completeness
  - Non ambiguity
- A behavioural validation within a simulation environment
- Automatic generation of certified code
- Formal proof

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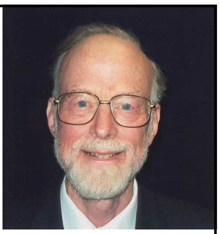


There are two ways of constructing a software design. One way is to make it so simple that there are obviously no deficiencies. And the other way is to make it so complicated that there are no obvious deficiencies.

Professor C. A. R. Hoare
The 1980 Turing award lecture

Wikipedia

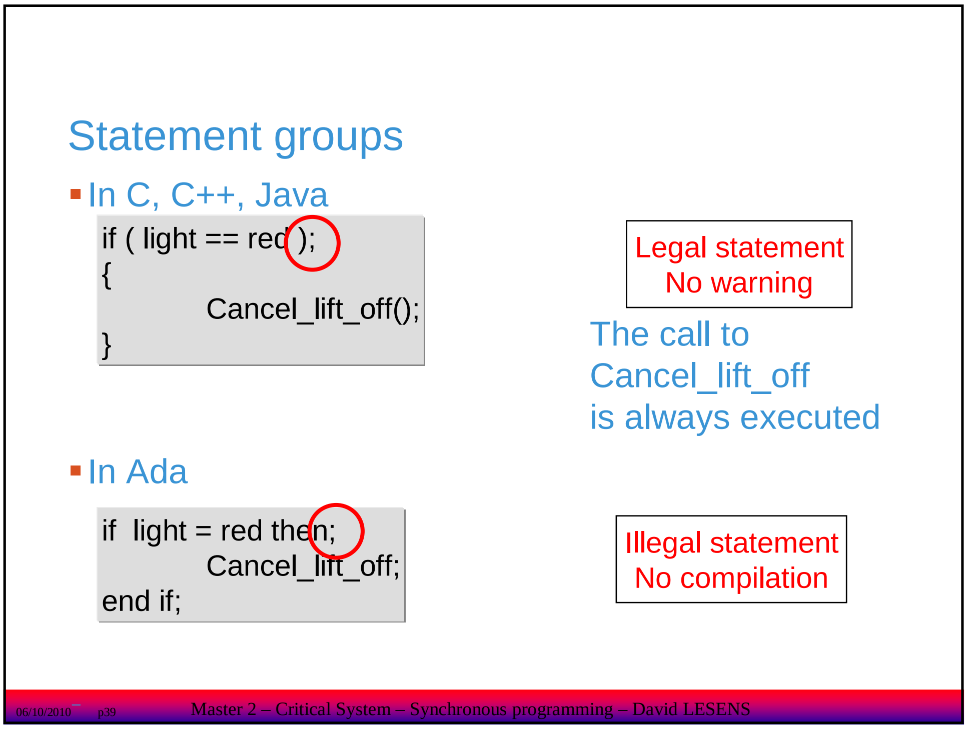
Formal semantics of programming languages

In theoretical computer science, formal semantics is the field concerned with the rigorous mathematical study of the meaning of programming languages and models of computation

Syntax

- Is it only what you say that matters?
- And not so much how it is said?

- A good syntax shall be
  - Clear
  - Unambiguous
  - Intuitive



Statement groups

- In C, C++, Java

```
if ( light == red );
{
            Cancel_lift_off();
}
```

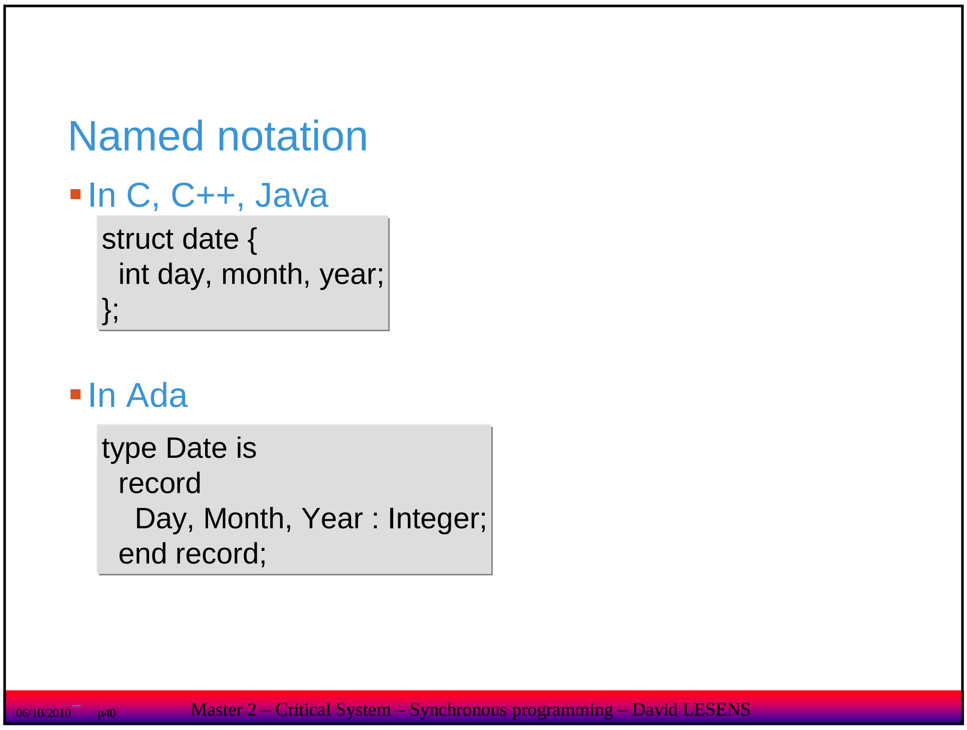
Legal statement
No warning

The call to
Cancel_lift_off
is always executed

- In Ada

```
if  light = red then;
            Cancel_lift_off;
end if;
```

Illegal statement
No compilation



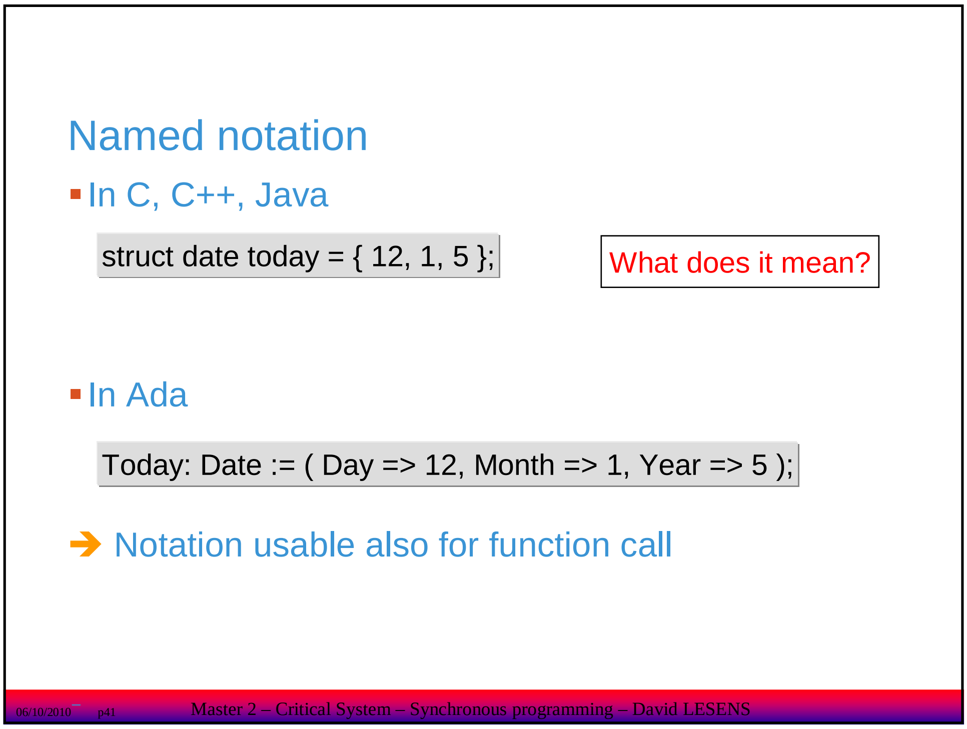
Named notation

- In C, C++, Java

```
struct date {
  int day, month, year;
};
```

- In Ada

```
type Date is
  record
    Day, Month, Year : Integer;
  end record;
```



Named notation

- In C, C++, Java

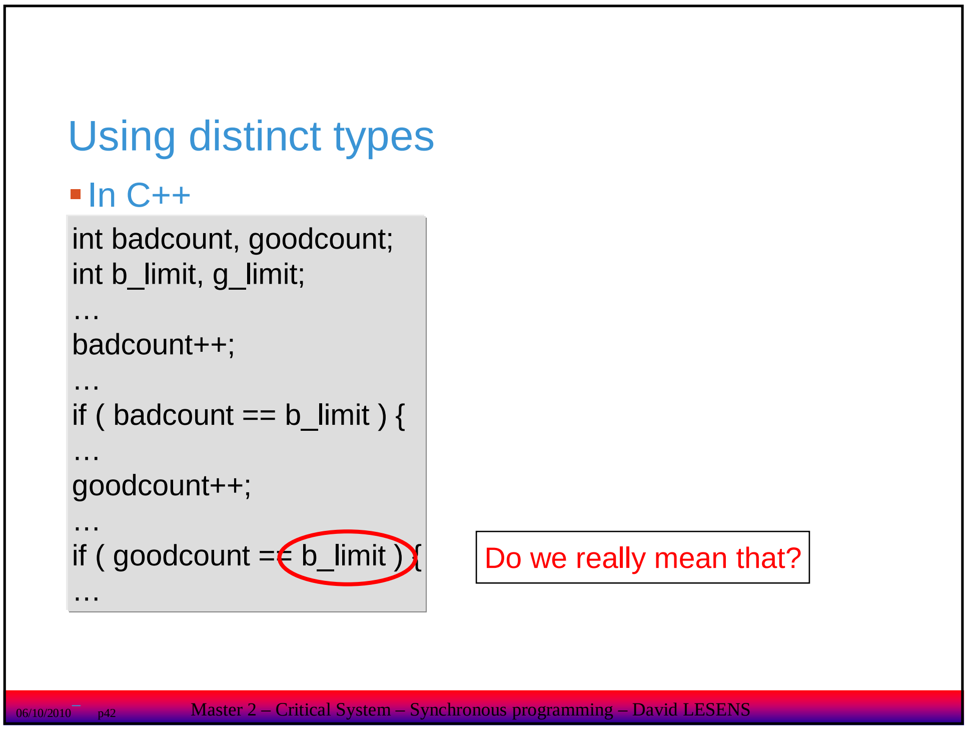
```
struct date today = { 12, 1, 5 };
```

What does it mean?

- In Ada

```
Today: Date := ( Day => 12, Month => 1, Year => 5 );
```

➔ Notation usable also for function call

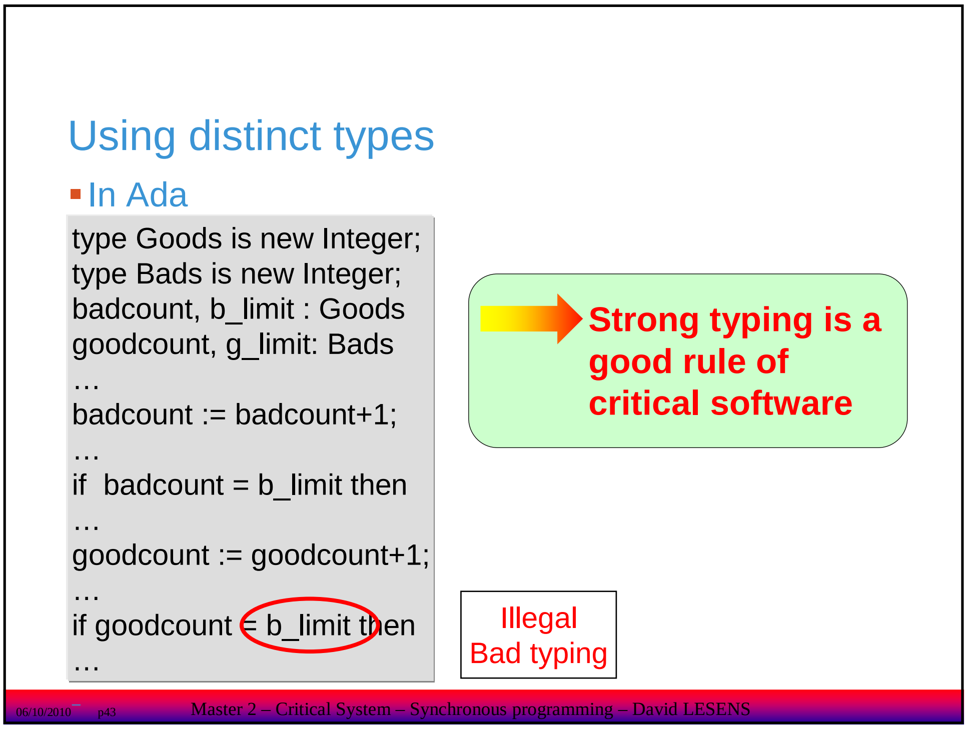


Using distinct types

- In C++

```
int badcount, goodcount;
int b_limit, g_limit;
…
badcount++;
…
if ( badcount == b_limit ) {
…
goodcount++;
…
if ( goodcount == b_limit ) {
…
```

Do we really mean that?



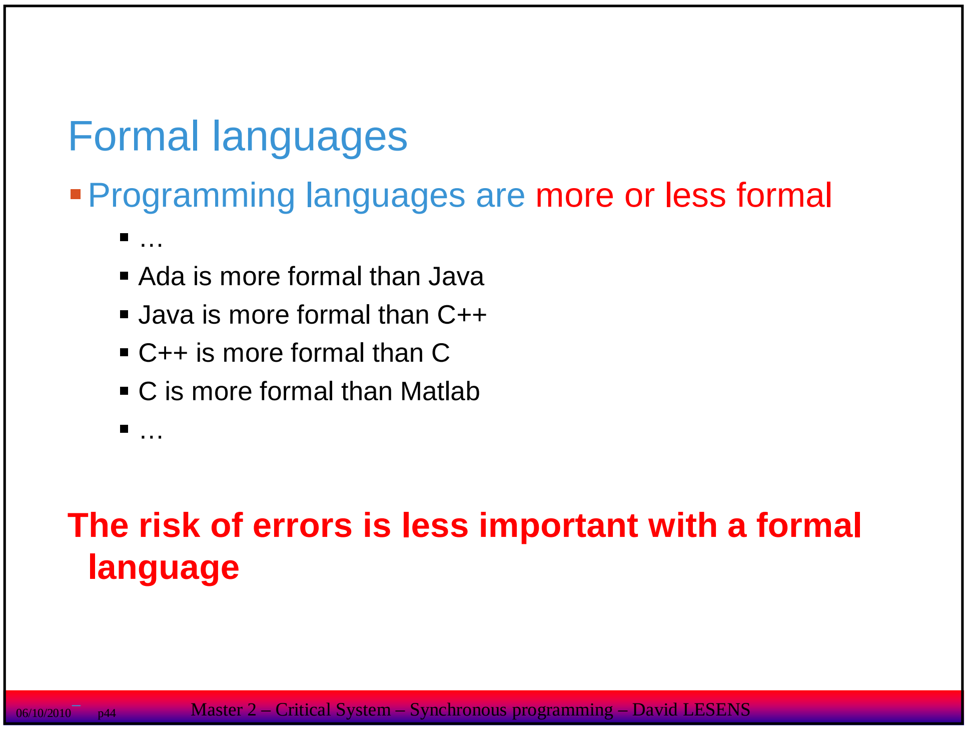
Using distinct types

- In Ada

```
type Goods is new Integer;
type Bads is new Integer;
badcount, b_limit : Goods
goodcount, g_limit: Bads
…
badcount := badcount+1;
…
if  badcount = b_limit then
…
goodcount := goodcount+1;
…
if goodcount = b_limit then
…
```

Illegal
Bad typing

Strong typing is a good rule of critical software



Formal languages

- Programming languages are more or less formal
  - …
  - Ada is more formal than Java
  - Java is more formal than C++
  - C++ is more formal than C
  - C is more formal than Matlab
  - …

The risk of errors is less important with a formal language

```
case State is
 when State1 =>
  Guard1 := X < 3;
  Guard2 := X > 3;
  if (EVENT1 and (Guard1 or Guard2)) then
    if (Guard1) then
     X := 5;
     State := State2;
    else
     if (Guard2) then
       X := 6;
     end if;
     State := State3;
    end if;
  end if;
 when State2 =>
  if (EVENT1) then
    X := 7;
    State := State1;
  end if;
 when State3 =>
  if (EVENT1 and EVENT1) then
    X := 8;
    State := State1;
  end if;
end case;
```

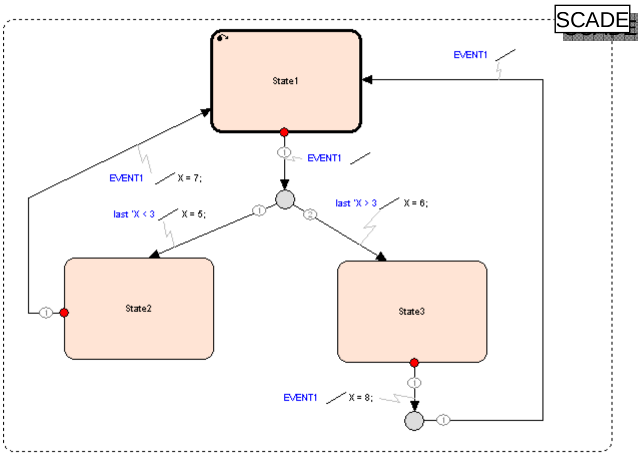
An other very simple example

Simple? Yes…

But what does this piece of code do?

Code (even Ada) is not an adequate way to communicate with system engineer

The same very simple example



➔ A graphical language with a high level of abstraction facilitates the communication

Overview

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Overview

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- Introduction to the Scade language
- Editing a Scade model
- Activation conditions
- Automata
- Arrays
- Iterations
- Global flows: Sensors and probes
- Genericity

Wikipedia

Need of deterministic algorithm

- In computer science, a deterministic algorithm is an algorithm which, in informal terms, behaves predictably
- Given a particular input, it will always produce the same output, and the underlying machine will always pass through the same sequence of states

Wikipedia

Determinism and ECSS

ECSS-Q-80C

- 6.2.3 Handling of critical software
- 6.2.3.2 The supplier shall define and apply measures to assure the dependability and safety of critical software. These measures can include:
  - …
  - prohibiting the use of language commands and features that are unpredictable;
  - use of **formal design language for formal proof**;

Synchronous languages

Semantics = synchronous hypothesis

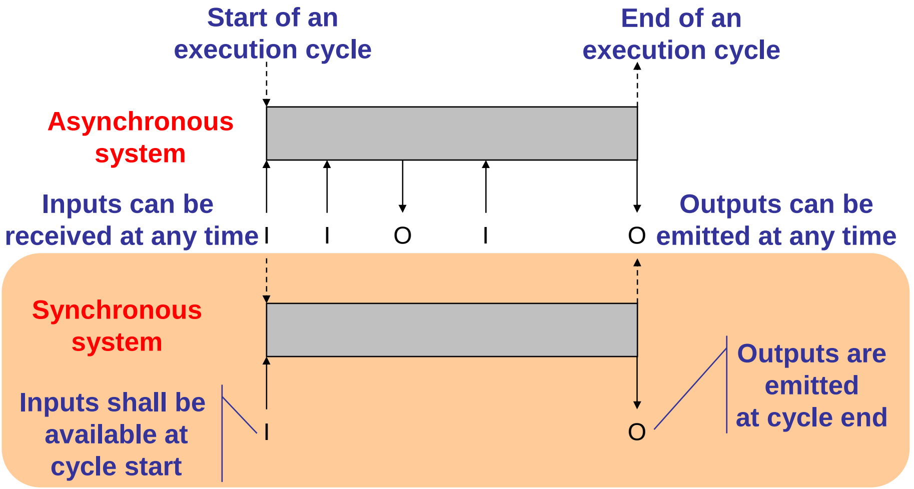
- Existence of a global clock
  - Software cyclically activated
  - Inputs read at the cycle beginning
  - Outputs delivered at cycle end

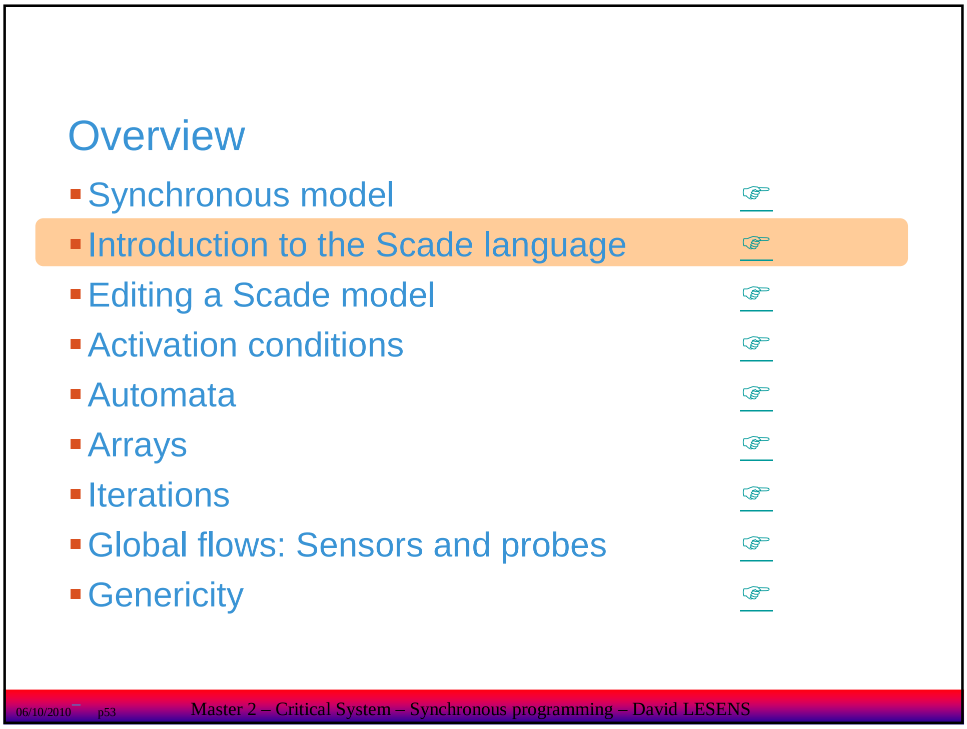
    (read / write forbidden during the cycle)
- The cycle execution duration shall theoretically be null

  ➔ No cycle overflow
- Mono-tasking

➔ Ensures the determinism

Asynchronous versus synchronous


Start of an execution cycle
End of an execution cycle
Asynchronous system
Inputs can be received at any time
I
I
O
I
O
Outputs can be emitted at any time
Synchronous system
Inputs shall be available at cycle start
I
O
Outputs are emitted at cycle end



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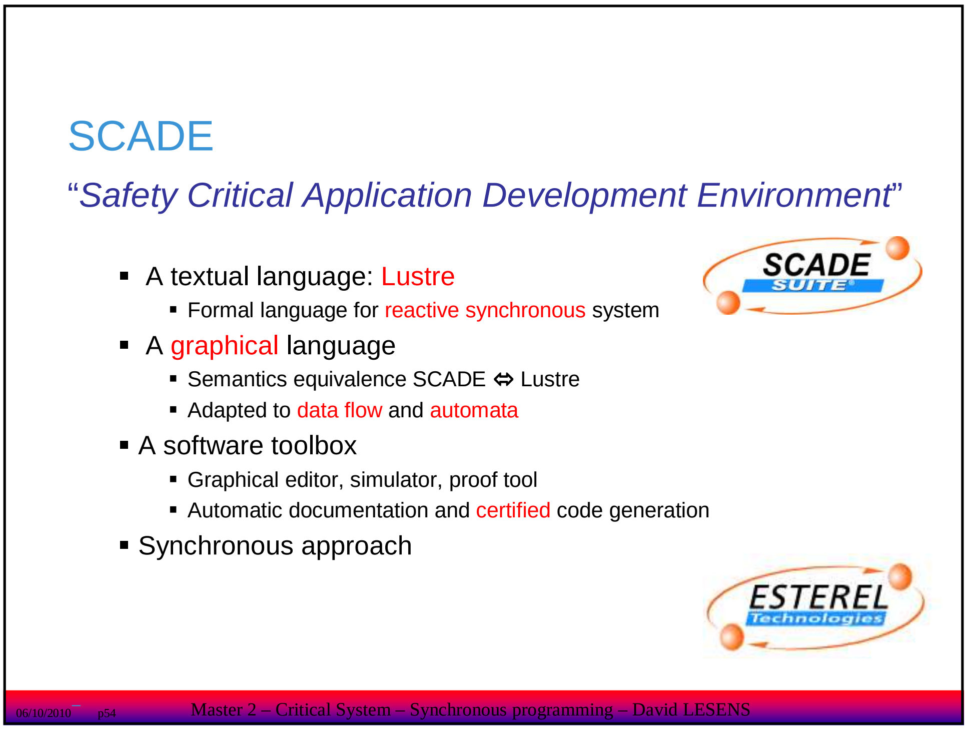
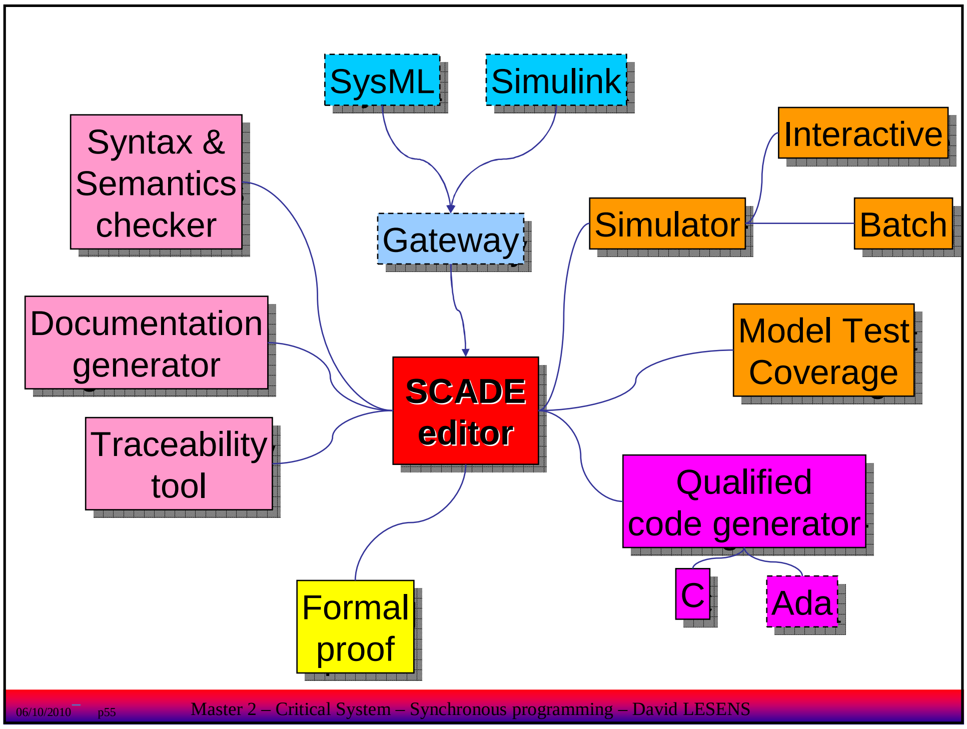


SCADE

"*Safety Critical Application Development Environment*"

- A textual language: Lustre
  - Formal language for reactive synchronous system
- A graphical language
  - Semantics equivalence SCADE ⇔ Lustre
  - Adapted to data flow and automata
- A software toolbox
  - Graphical editor, simulator, proof tool
  - Automatic documentation and certified code generation
- Synchronous approach



SCADE editor

SysML

Simulink

Gateway

Syntax & Semantics checker

Documentation generator

Traceability tool

Formal proof

Simulator

Interactive

Batch

Model Test Coverage

Qualified code generator

C

Ada

Time in Scade

- Global clock (known by all processes)
  - Time = discrete sequence of tick t_0, t_1, t_2, etc.
  - At each tick t_i a cycle is running
- Variable = flow which takes at each tick a unique value

  Example: integer variable x

	t_0	t_1	t_2	t_3	t_4	t_5
x	5	8	2	3	13	5

Operators

- An operator acts on flows of values (and not on values)

Example

- Operator « + »: int_n x int_n → int_n

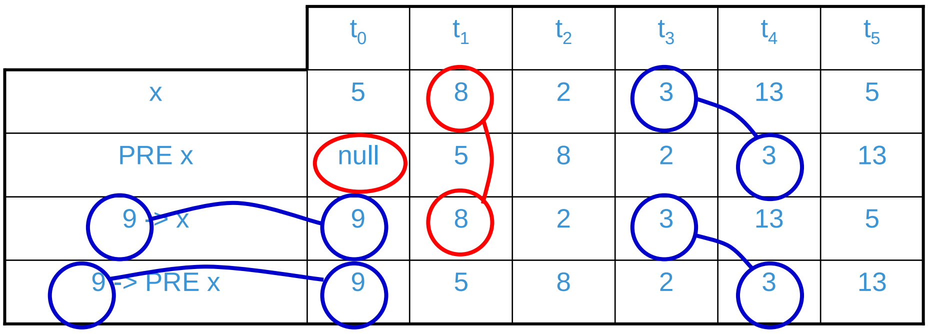
	t_0	t_1	t_2	t_3	t_4	t_5
x	5	8	2	3	13	5
x + x	10	16	4	6	26	10

Temporal operators

- The “PRE” operator takes as input a data flow (i.e. a variable) and returns its value at the previous tick.

  At initial tick, its value is undefined.
- The “→” operator takes as input an initialisation value and a data flow of the same type. It returns an identical data flow, except for the initial value.

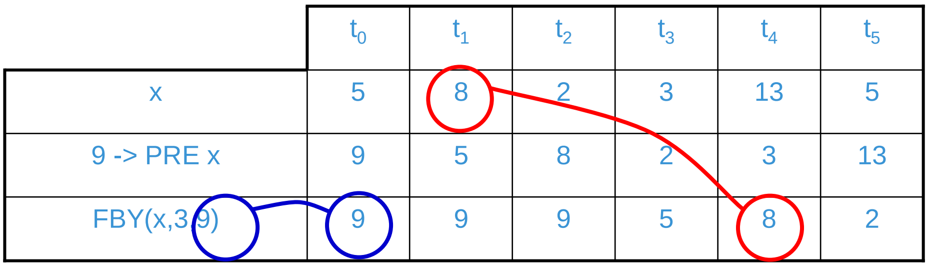
Example



	t_0	t_1	t_2	t_3	t_4	t_5
x	5	8	2	3	13	5
PRE x	null	5	8	2	3	13
9 -> x	9	8	2	3	13	5
9 -> PRE x	9	5	8	2	3	13

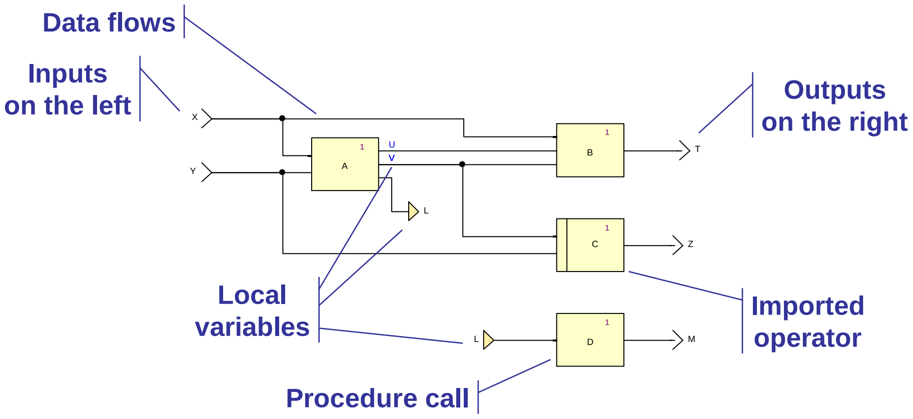
“Follow by” operator

$$\mathrm{FBY}(\ x,\ n,\ init\ ) = init \rightarrow \underbrace{(\ \mathrm{PRE}\ (\ \mathrm{PRE}\ \ldots\ x\ )\ )}_{n\ \text{times}}$$



	t_0	t_1	t_2	t_3	t_4	t_5
x	5	8	2	3	13	5
9 -> PRE x	9	5	8	2	3	13
FBY(x,3,9)	9	9	9	5	8	2

SCADE at a glance: Data Flow



Data flows

Inputs on the left

Outputs on the right

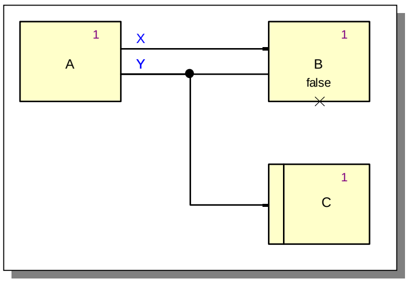
Local variables

Imported operator

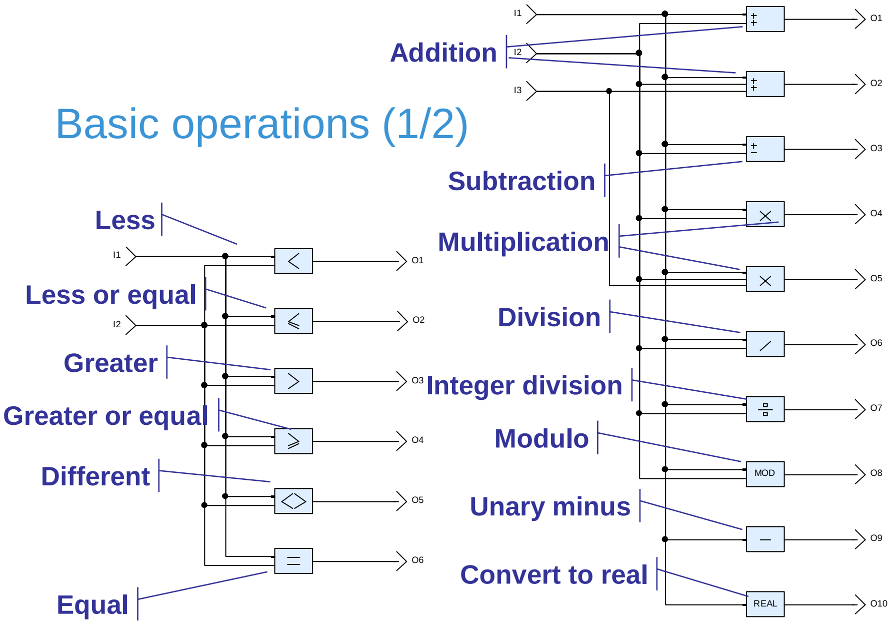
Procedure call

Textual versus graphical

```
( x, y ) = A();
B( x, y );
C( y )
```



Basic operations (1/2)


Addition

Subtraction

Multiplication

Division

Integer division

Modulo

Unary minus

Convert to real

Less

Less or equal

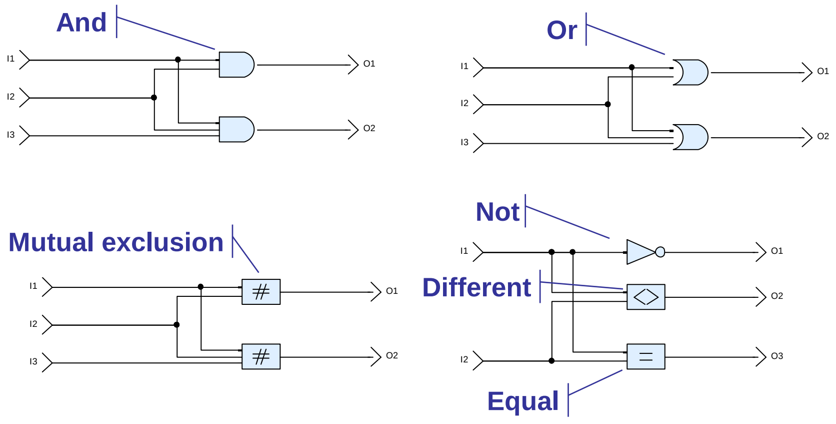
Greater

Greater or equal

Different

Equal

Basic operations (2/2)


And

Or

Mutual exclusion

Not

Different

Equal

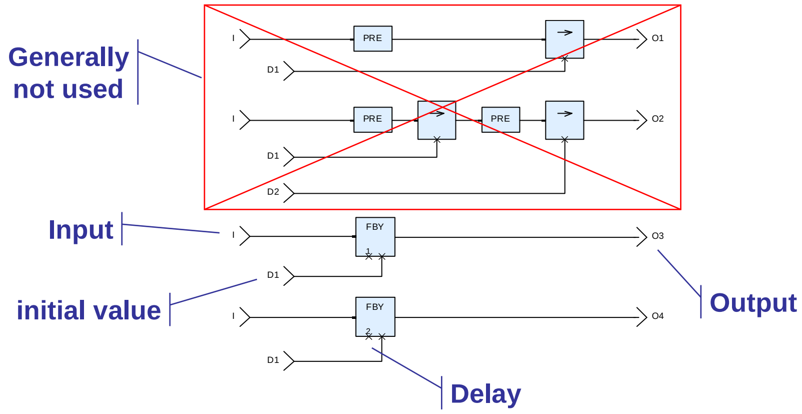
“Mutual exclusion” operator

$$\#: \underbrace{\text{bool} \times \text{bool} \times \ldots \times \text{bool}}_{\text{n times}} \rightarrow \text{bool}$$

Returns true if <u>at most</u> one of its inputs is true

e1	e2	e3	#(e1, e2, e3)
0	0	0	1
0	0	1	1
0	1	0	1
0	1	1	0
1	0	0	1
1	0	1	0
1	1	0	0
1	1	1	0

Delays



Generally not used

Input

initial value

Output

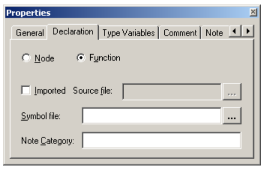
Delay

Node and function

y = f(x)

Function and nodes are represented by a rectangle

- A node has an internal state
- A function has **no** internal state



Properties

○ Node ● Function

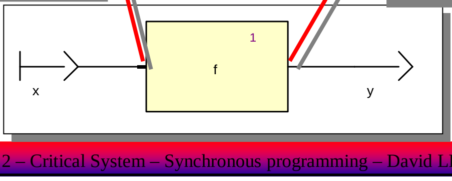
□ Imported Source file:

Symbol file:

Note Category:

Input parameters on the left

Output parameters on the right



Imported function / node

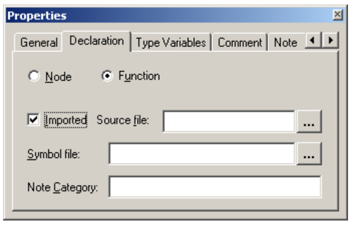
- Imported function

```
extern void C(
         bool Y );
```

- Imported node

```
extern void C_reset(
         outC_C *outC );
extern void C(
         bool Y,
         outC_C *outC );
```

Context to be defined by the developer



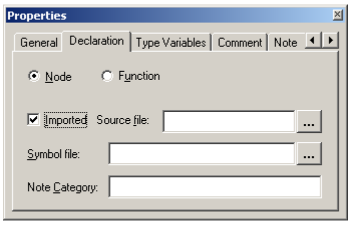
Properties

○ Node ● Function

☑ Imported Source file:

Symbol file:

Note Category:



Properties

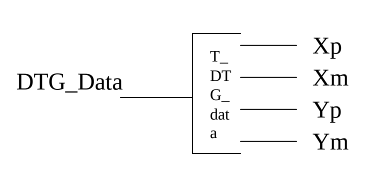
● Node ○ Function

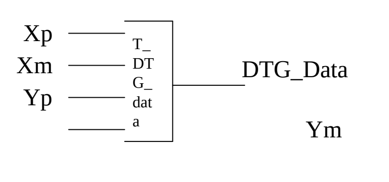
☑ Imported Source file:

Symbol file:

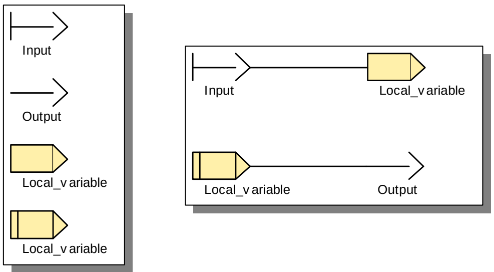
Note Category:

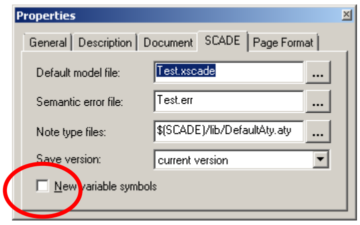
Data structure

	Xp := DTG_data.Xp
	Xm := DTG_data.Xm
	Yp := DTG_data.Yp
	Ym := DTG_data.Ym

	DTG_data.Xp := Xp
	DTG_data.Xm := Xm
	DTG_data.Yp := Yp
	DTG_data.Ym := Ym

Variables representation





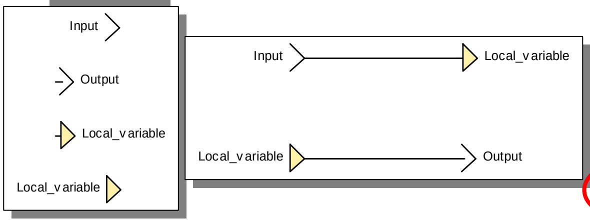
Default model file: Test.xscade

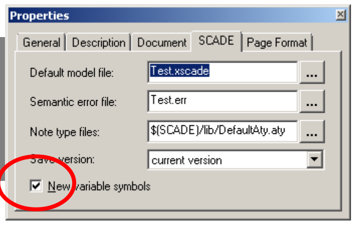
Semantic error file: Test.err

Note type files: $(SCADE)/lib/DefaultAty.aty

Save version: current version

□ New variable symbols





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☑ New variable symbols

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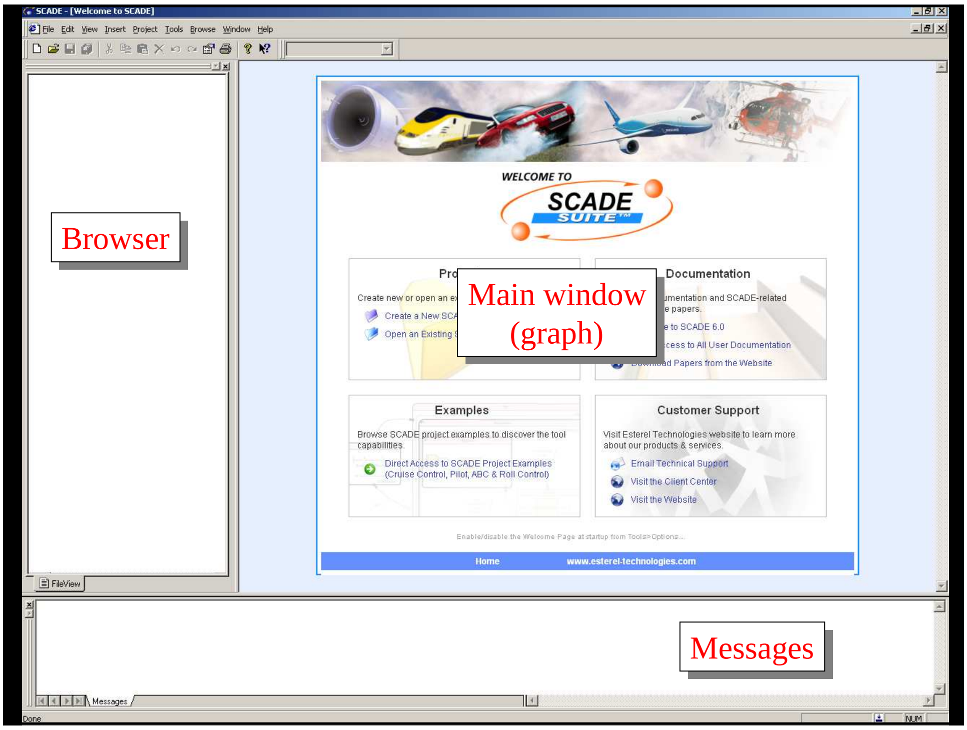

Create new or open an ex

Create a New SCA

Open an Existing S

umentation and SCADE-related e papers.

e to SCADE 6.0

ccess to All User Documentation

Download Papers from the Website

Browse SCADE project examples to discover the tool capabilities.

Direct Access to SCADE Project Examples (Cruise Control, Pilot, ABC & Roll Control)

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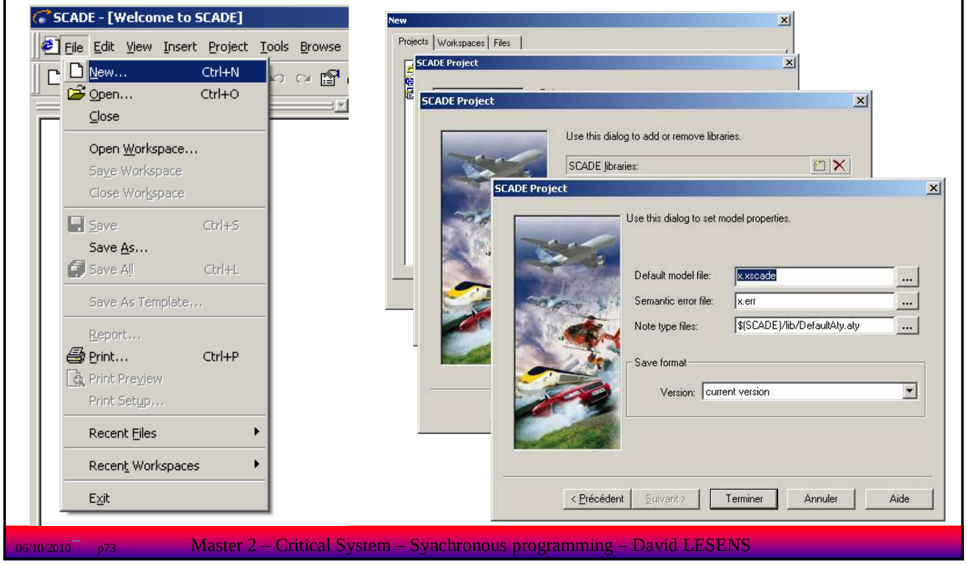
Visit the Website

Enable/disable the Welcome Page at startup from Tools>Options...

Creating a new project



Use this dialog to add or remove libraries.

SCADE libraries:

Use this dialog to set model properties.

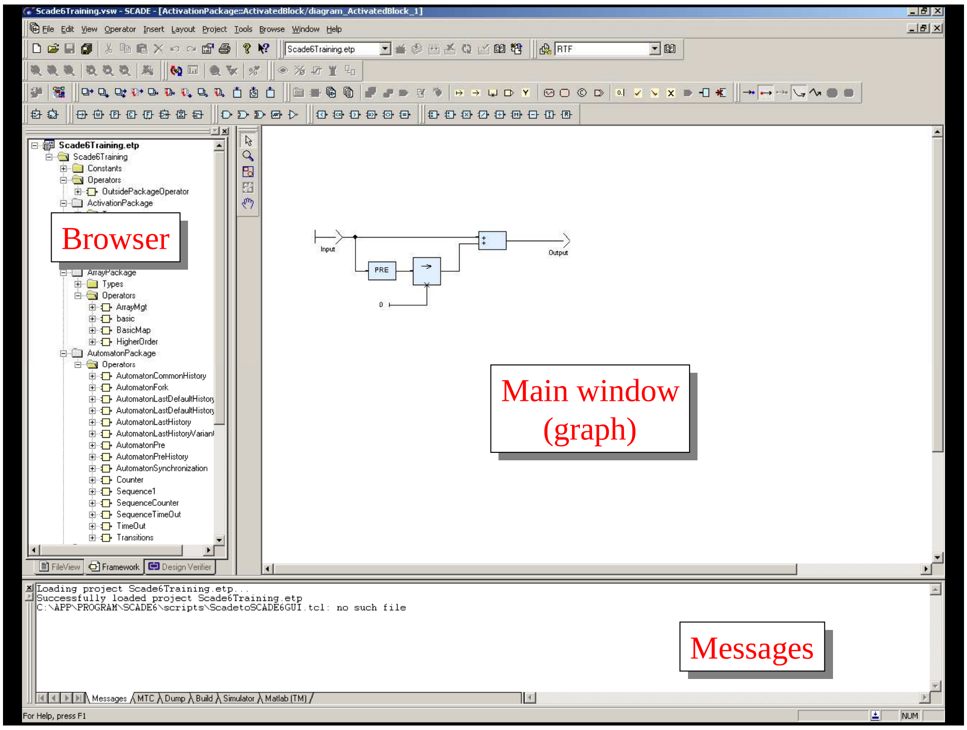
Default model file: x.xscade

Semantic error file: x.err

Note type files: $(SCADE)/lib/DefaultAty.aty

Save format

Version: current version



Browser

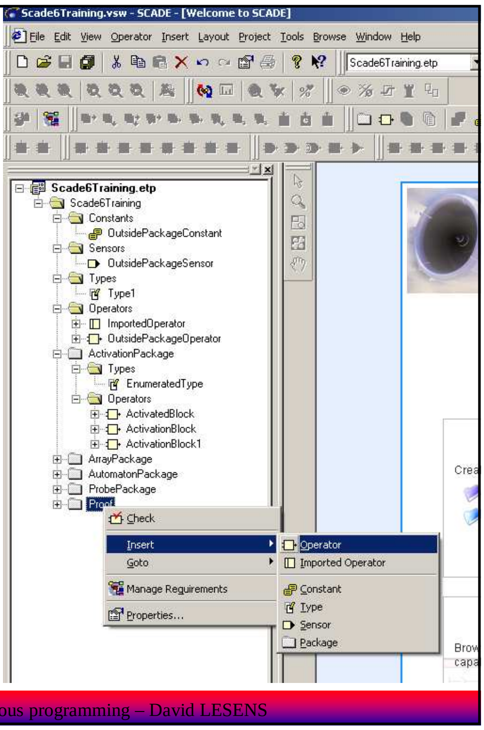
Main window (graph)

Messages

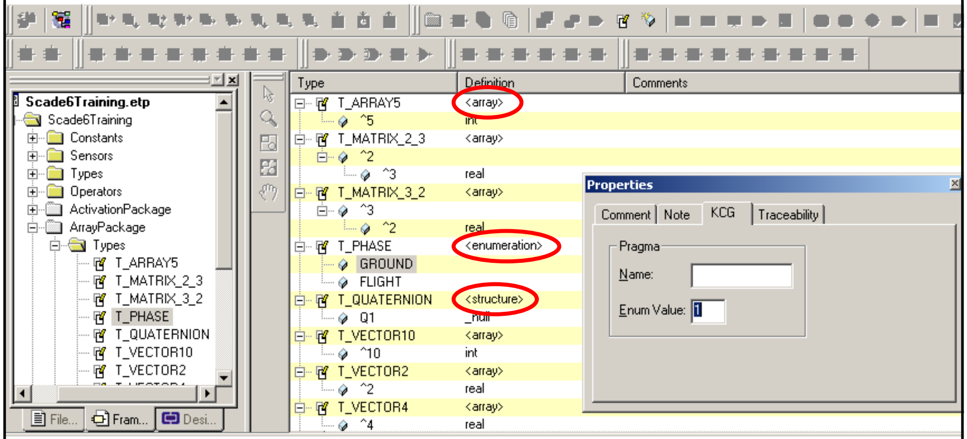
```
Loading project Scade6Training.etp...
Successfully loaded project Scade6Training.etp
C:\APP\PROGRAM\SCADE6\scripts\ScadetoSCADE6GUI.tcl: no such file
```

Packages

- Definitions of
  - Scade operators
  - Imported operators
  - Constants
  - Types
  - Sensors
  - Packages
- Inside or outside a package



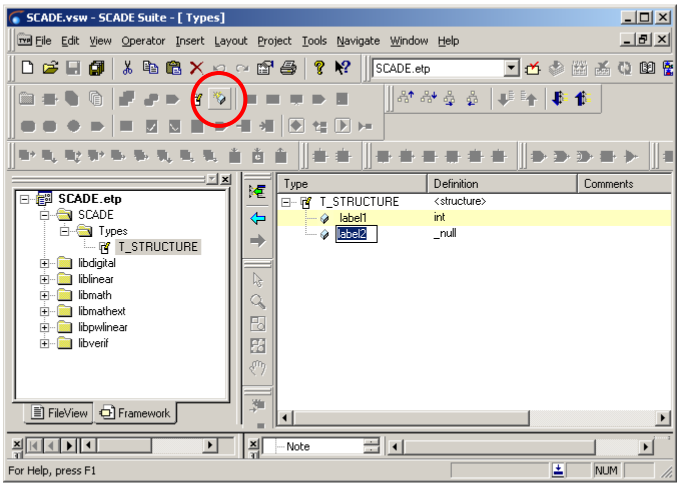
Management of types (1/3)



Type	Definition	Comments
T_ARRAY5	<array>	
^5	int	
T_MATRIX_2_3	<array>	
^2		
^3	real	
T_MATRIX_3_2	<array>	
^3		
^2	real	
T_PHASE	<enumeration>	
GROUND		
FLIGHT		
T_QUATERNION	<structure>	
Q1	_null	
T_VECTOR10	<array>	
^10	int	
T_VECTOR2	<array>	
^2	real	
T_VECTOR4	<array>	
^4	real	

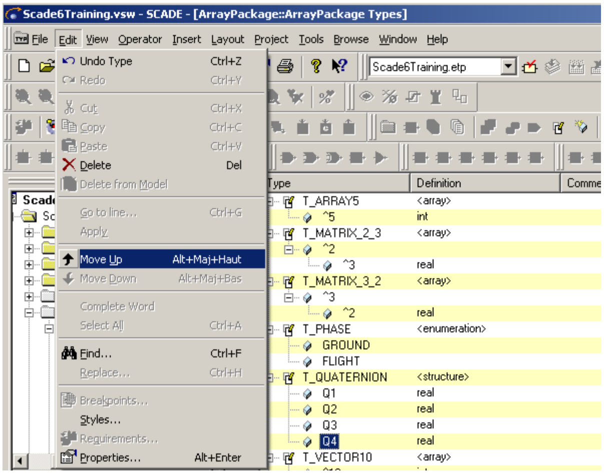
Name:
Enum Value: 1

Management of types (2/3)



Type	Definition	Comments
T_STRUCTURE	<structure>	
label1	int	
label2	_null	

Management of types (3/3)



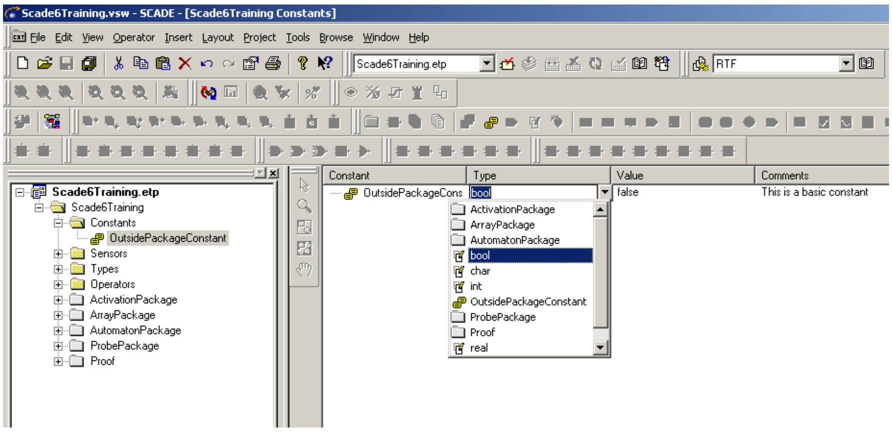
Type	Definition	Comme
T_ARRAY5	<array>	
^5	int	
T_MATRIX_2_3	<array>	
^2		
^3	real	
T_MATRIX_3_2	<array>	
^3		
^2	real	
T_PHASE	<enumeration>	
GROUND		
FLIGHT		
T_QUATERNION	<structure>	
Q1	real	
Q2	real	
Q3	real	
Q4	real	
T_VECTOR10	<array>	

Integers and reals

- Integers
  - Binary 0b01001
  - Octal 0563
  - Decimal 9637
  - Hexadecimal 0xAF6C
- Encoding
  - short, int, long
  - Float, double

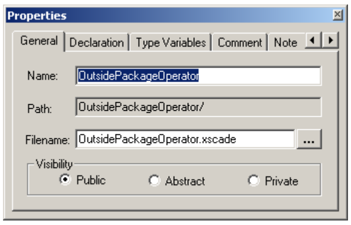
} Shall be defined by the user

Defining a constant



Constant	Type	Value	Comments
OutsidePackageCons	bool	false	This is a basic constant

Changing an object properties

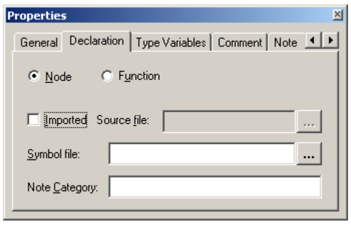


Name: OutsidePackageOperator

Path: OutsidePackageOperator/

Filename: OutsidePackageOperator.xscade

Visibility: ● Public ○ Abstract ○ Private



● Node ○ Function

□ Imported Source file:

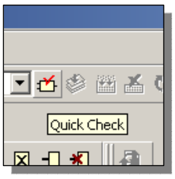
Symbol file:

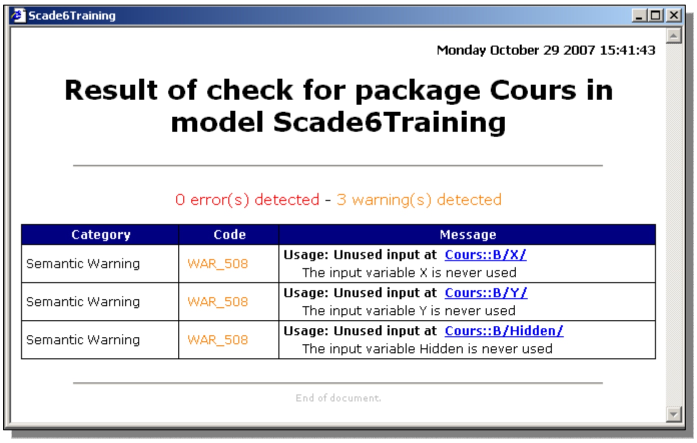
Note Category:

Keyword list

- Scade keywords
  - abstract, activate, and, assume, automaton, bool, case, char, clock, const, default, div, do, else, elsif, emit, end, enum, every, false, fby, final, flatten, fold, foldi, foldw, foldwi, function, guarantee, group, if, imported, initial, int, is, last, let, make, map, mapfold, mapi, mapw, mapwi, match, merge, mod, node, not, numeric, of, onreset, open, or, package, parameter, pre, private, probe, public, real, restart, resume, returns, reverse, sensor, sig, specialize, state, synchro, tel, then, times, transpose, true, type, unless, until, var, when, where, with, xor
- + Targeted programming language keywords

Quick check





Scade6Training

Monday October 29 2007 15:41:43

Result of check for package Cours in model Scade6Training

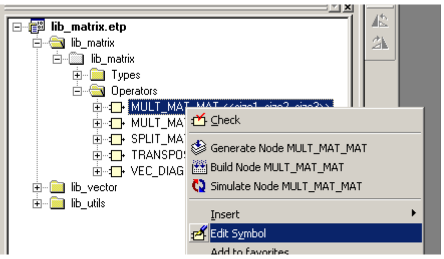
0 error(s) detected - 3 warning(s) detected

Category	Code	Message
Semantic Warning	WAR_508	**Usage: Unused input at** Cours::B/X/ The input variable X is never used
Semantic Warning	WAR_508	**Usage: Unused input at** Cours::B/Y/ The input variable Y is never used
Semantic Warning	WAR_508	**Usage: Unused input at** Cours::B/Hidden/ The input variable Hidden is never used

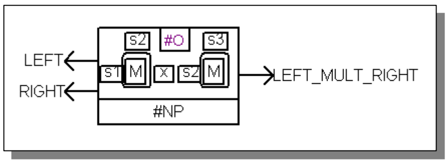
End of document.

The quick check performs syntax and semantics verification
It shall be frequently used

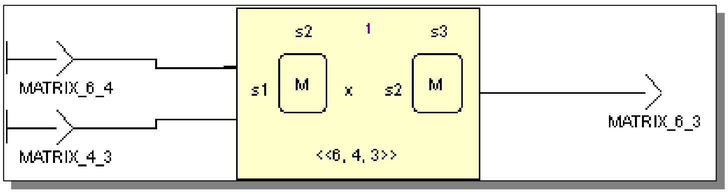
Symbol editor



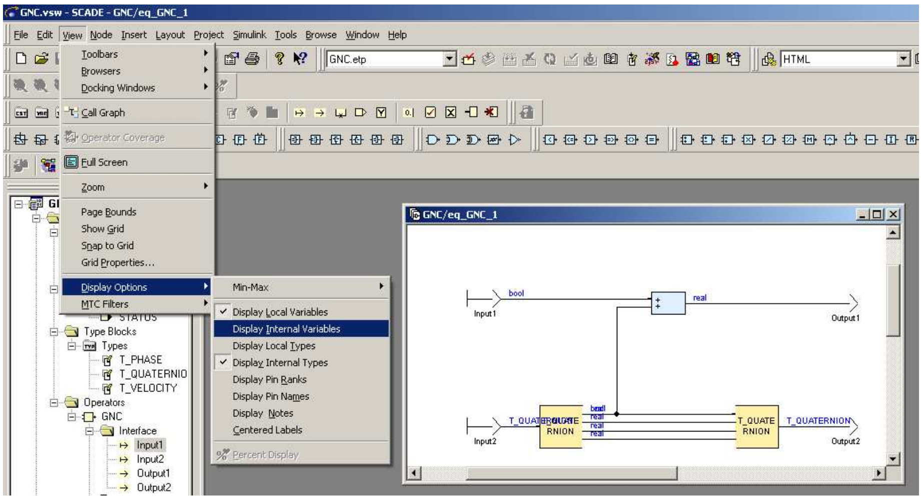
Edition of the symbol



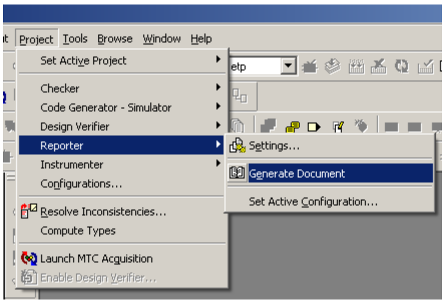
Use of the symbol

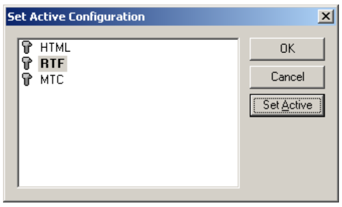


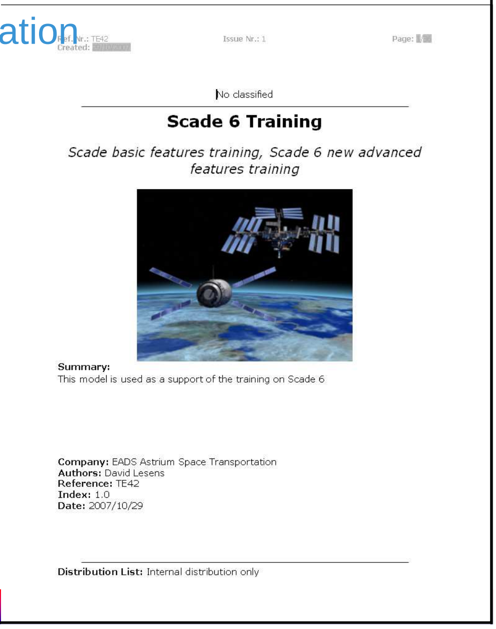
Display types / variable names / …



Generation of documentation






Ref. Nr.: TE42 Issue Nr.: 1 Page: 1/36
Created: 29/10/2007

No classified

Scade 6 Training

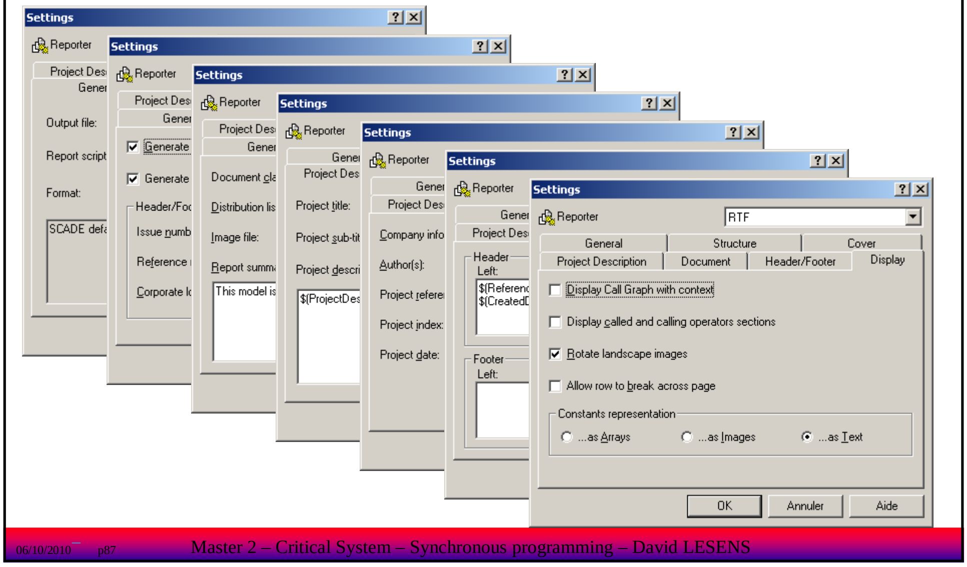
Scade basic features training, Scade 6 new advanced features training

Summary:
This model is used as a support of the training on Scade 6

Company: EADS Astrium Space Transportation
Authors: David Lesens
Reference: TE42
Index: 1.0
Date: 2007/10/29

Distribution List: Internal distribution only

Report customization



Settings

Reporter: RTF

General | Structure | Cover | Project Description | Document | Header/Footer | Display

☐ Display Call Graph with context

☐ Display called and calling operators sections

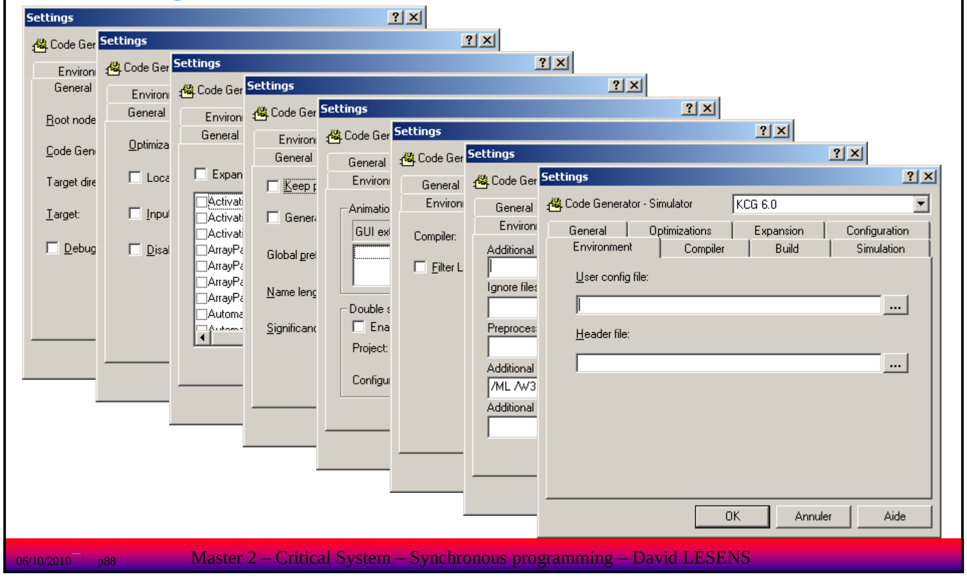
☑ Rotate landscape images

☐ Allow row to break across page

Constants representation

○ ...as Arrays ○ ...as Images ● ...as Text

Code generation customization



Settings

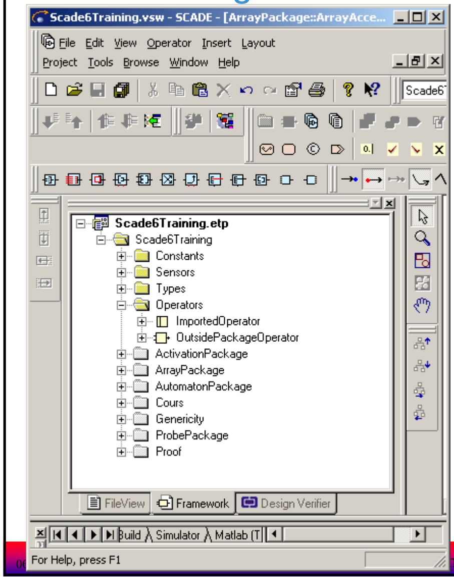
Code Generator - Simulator: KCG 6.0

General | Optimizations | Expansion | Configuration | Environment | Compiler | Build | Simulation

User config file:

Header file:

File management



Scade6Training.xscade
ImportedOperator.xscade
OutsidePackageOperator.xscade
ActivationPackage.xscade
ArrayPackage.xscade
AutomatonPackage.xscade
Cours.xscade
Genericity.xscade
ProbePackage.xscade
Proof.xscade

Documentation

- **Welcome to SCADE 6.o**
- **Getting Started with SCADE**
- **Scade Language Tutorial**
- **Scade Language Primer**
- **Scade Language Reference Manual**
- **SCADE User Manual**
- **SCADE Technical Manual**
- **SCADE Libraries Manual**
- **SCADE UML Metamodel Card**
- **SCADE Gateway for Rhapsody Guidelines**
- **Simulink™ Gateway Guidelines**
- **Simulink™ Modeling Guidelines**
- **RTOS Wrapper Guidelines**

About Requirements Management Gateway documentation, check from RMG interface at Help > Documentation or Coupling Notes

Overview

- Synchronous model ☞
- Introduction to the Scade language ☞
- Editing a Scade model ☞
- **Activation conditions** ☞
- Automata ☞
- Arrays ☞
- Iterations ☞
- Global flows: Sensors and probes ☞
- Genericity ☞

“IF” operator

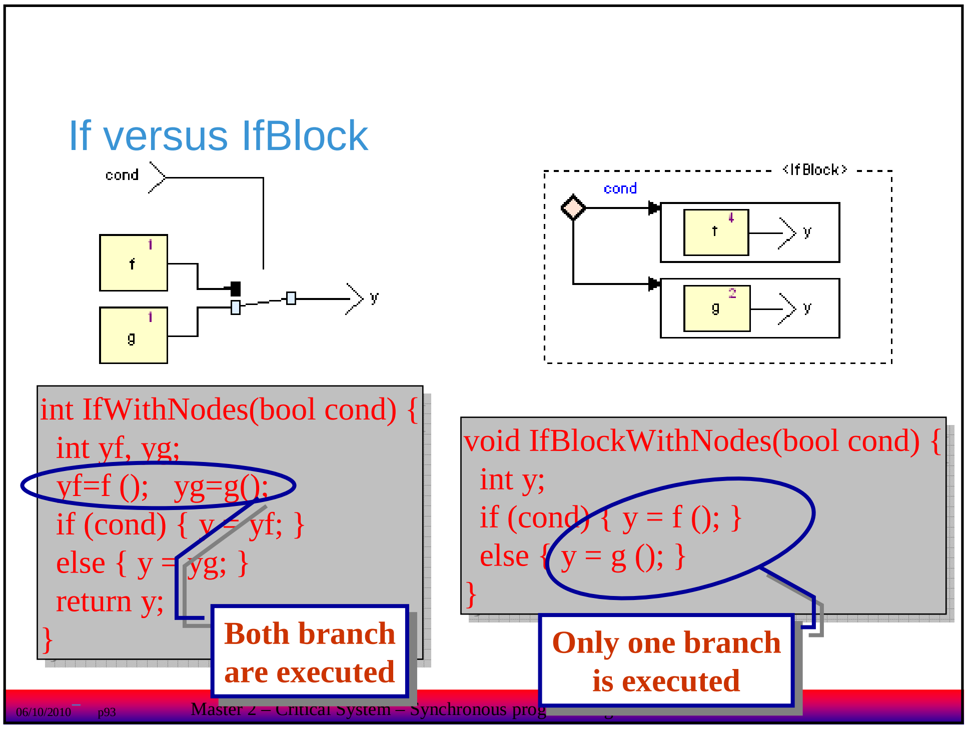
x = if b then y else z

If “b” is true, “x” takes the value “y”,
else, “x” takes the value “z”

Note:

Does not mean

If “b” is true, execute “y”,
else, execute “z”



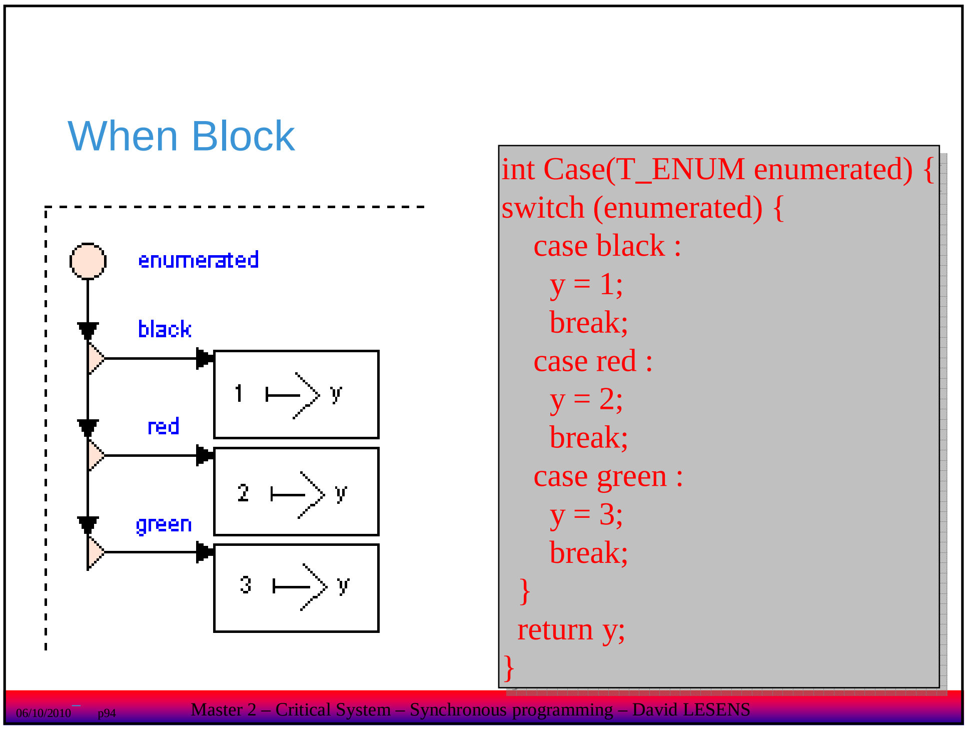
If versus IfBlock

```
int IfWithNodes(bool cond) {
  int yf, yg;
  yf=f ();   yg=g();
  if (cond) { y = yf; }
  else { y = yg; }
  return y;
}
```

Both branch are executed

```
void IfBlockWithNodes(bool cond) {
  int y;
  if (cond) { y = f (); }
  else { y = g (); }
}
```

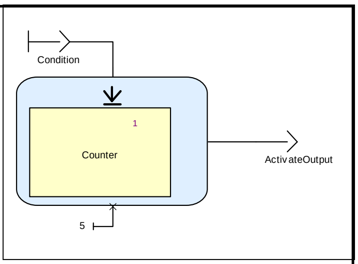
Only one branch is executed



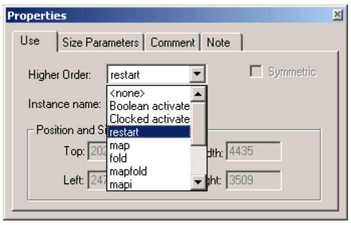
When Block

```
int Case(T_ENUM enumerated) {
switch (enumerated) {
   case black :
     y = 1;
     break;
   case red :
     y = 2;
     break;
   case green :
     y = 3;
     break;
  }
  return y;
}
```

Activation conditions



- Activation condition
  - Condition true = Block activated
  - Condition false = Previous outputs used (was “condact” in Scade 5)
    <u>or</u> Default values
  - Init values before first use
- Restart condition
  - Condition true = Internal memory reset


Properties

Use | Size Parameters | Comment | Note

Higher Order: restart

Instance name:

Position and Size

Top: 20

Left: 24

Width: 4435

Height: 3509

Activation: Example (1/3)

x = a + b, <u>initial</u> default value 5, activation condition c

y = a + b, default value 5, activation condition c

Default values

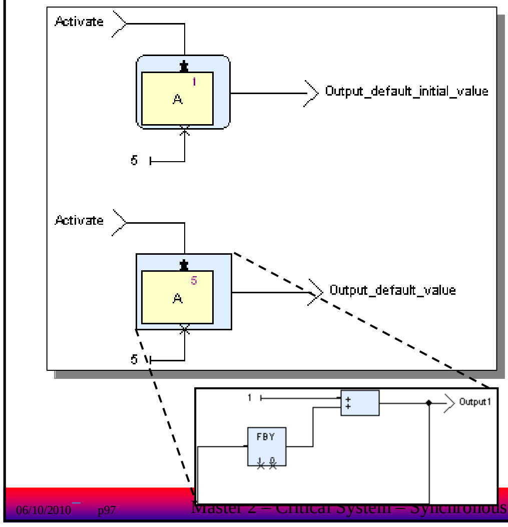
Computed values

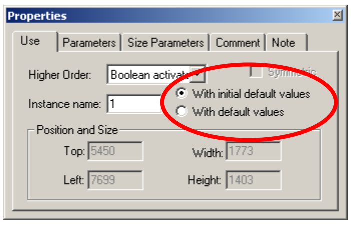
c	0	0	1	0	1
a	3	6	3	2	3
b	3	2	-1	1	4
x	5	5	2	2	7
y	5	5	2	5	7

Last computed values

Default value

Activation: Example (2/3)




Properties

Use | Parameters | Size Parameters | Comment | Note

Higher Order: Boolean activat

□ Symmetric

Instance name: 1

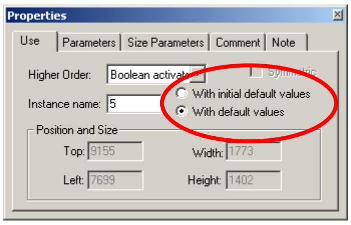
● With initial default values

○ With default values

Position and Size

Top: 5450 Width: 1773

Left: 7699 Height: 1403


Properties

Use | Parameters | Size Parameters | Comment | Note

Higher Order: Boolean activat

□ Symmetric

Instance name: 5

○ With initial default values

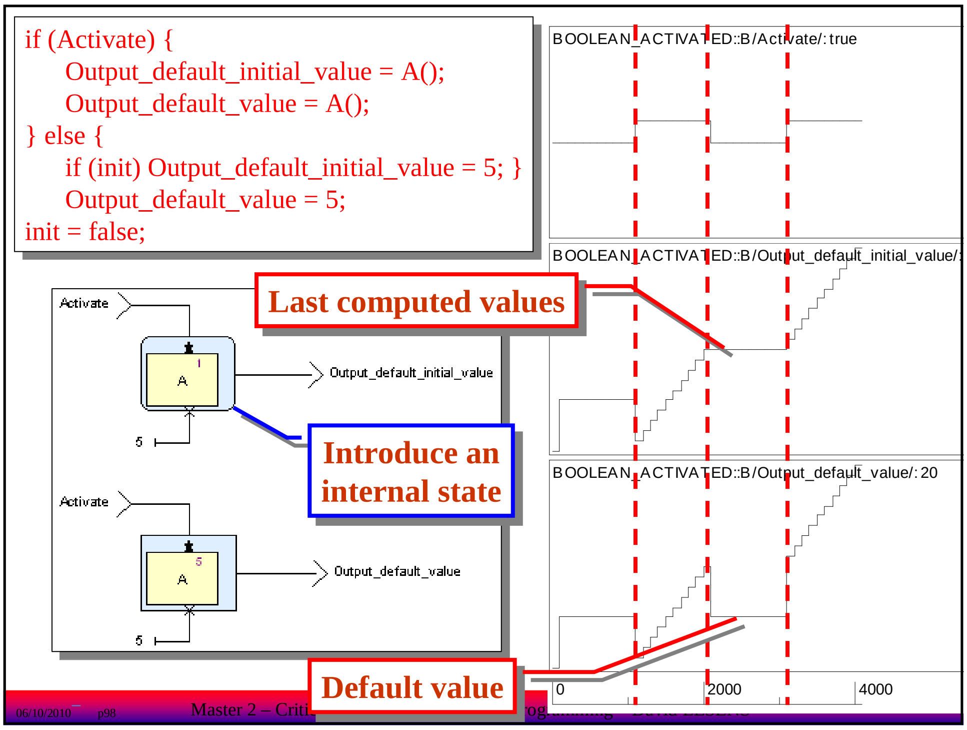
● With default values

Position and Size

Top: 9155 Width: 1773

Left: 7699 Height: 1402

```
if (Activate) {
    Output_default_initial_value = A();
    Output_default_value = A();
} else {
    if (init) Output_default_initial_value = 5; }
    Output_default_value = 5;
init = false;
```

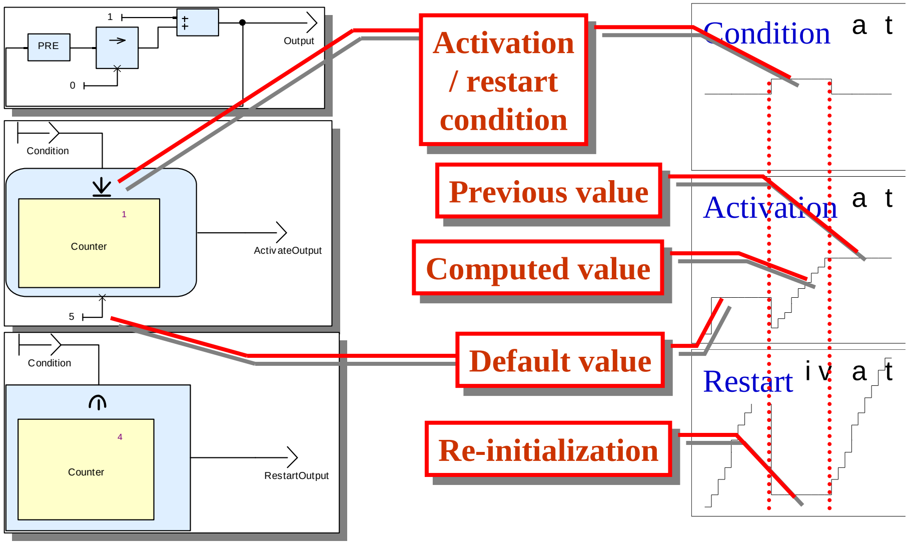


Last computed values

Introduce an internal state

Default value

Activation and restart



Activation / restart condition

Previous value

Computed value

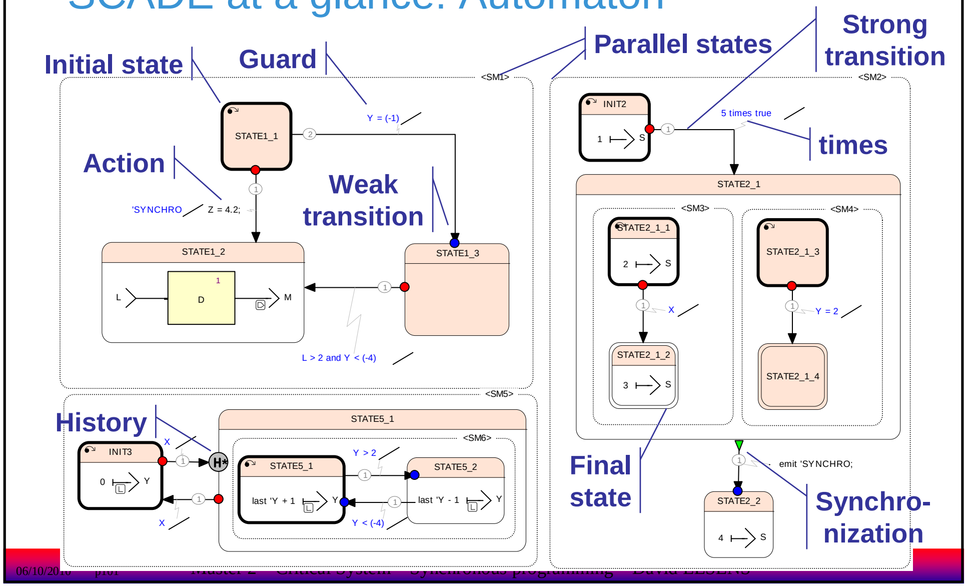
Default value

Re-initialization

Overview

- Synchronous model
- Introduction to the Scade language
- Editing a Scade model
- Activation conditions
- Automata
- Arrays
- Iterations
- Global flows: Sensors and probes
- Genericity

SCADE at a glance: Automaton



Initial state

Guard

Parallel states

Strong transition

Action

Weak transition

times

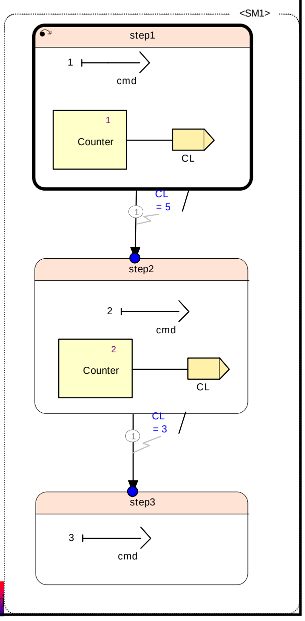
History

Final state

Synchronization

Data flow and automata

- A node is composed of
  - Equations (data-flow)
  - Automata (event driven)
- An automaton is composed of
  - States
  - Transitions
- A state is composed of
  - Equations
  - Automata



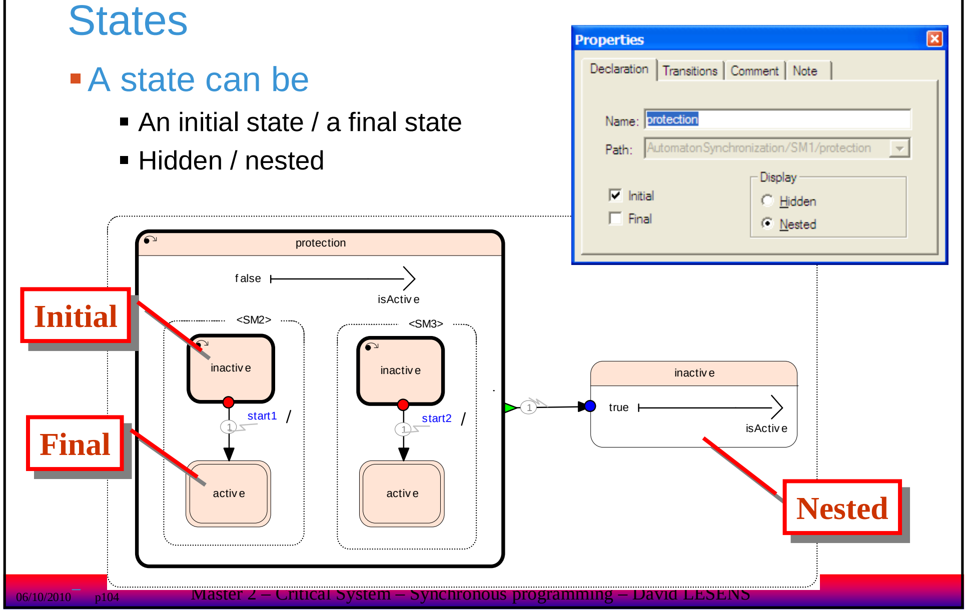
Principles of Automata

- Semantics equivalence
  - There exists a data-flow model semantically equivalent to any automaton
- Automaton scheduling
  - At most one transition fired *per cycle*
  - Exactly one active state per *cycle*

    (except then parallel states are defined)

States

- A state can be
  - An initial state / a final state
  - Hidden / nested



Properties

Declaration | Transitions | Comment | Note

Name: protection

Path: AutomatonSynchronization/SM1/protection

☑ Initial

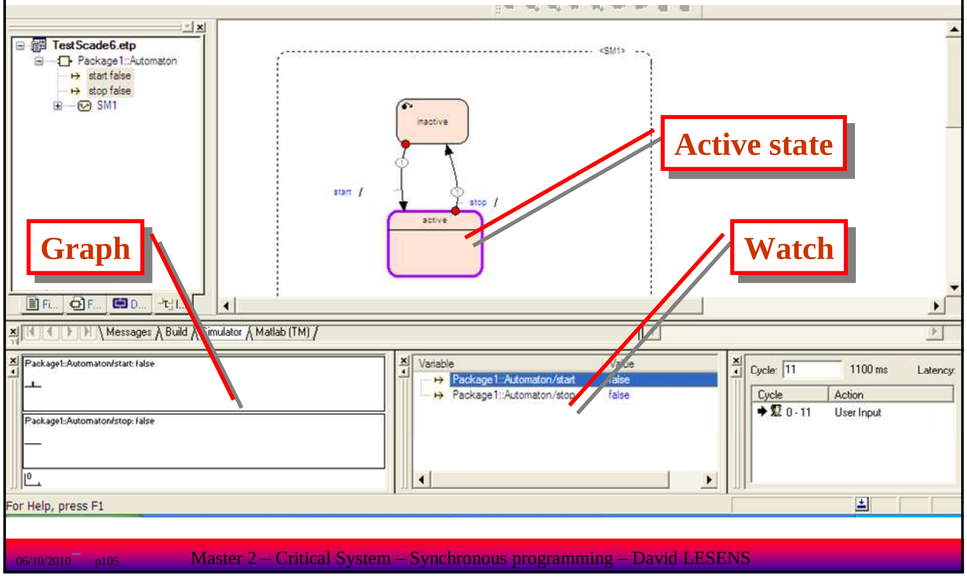
□ Final

Display

○ Hidden

● Nested

Automaton simulation



Active state

Graph

Watch

Package1::Automaton/start: false

Package1::Automaton/stop: false

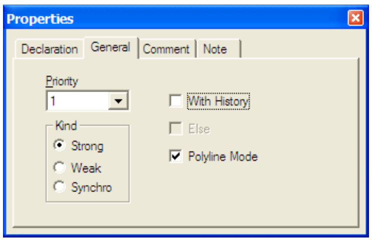
Variable	Value
Package1::Automaton/start	false
Package1::Automaton/stop	false

Cycle: 11 1100 ms Latency:

Cycle	Action
0 - 11	User Input

Transitions

- A transition can
  - have a **weak** pre-emption
  - have a **strong** pre-emption
  - be **synchronized**
- It can have
  - A guard
  - An action
- It has a priority
- It can be with or without a history

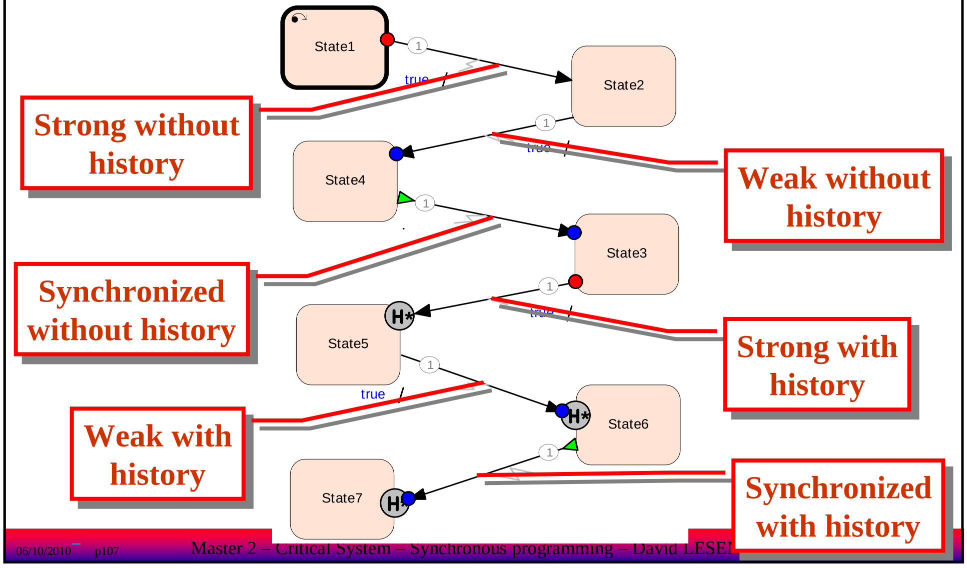


Priority: 1

Kind:
● Strong
○ Weak
○ Synchro

□ With History
□ Else
☑ Polyline Mode

Graphical transitions



Strong without history

Weak without history

Synchronized without history

Strong with history

Weak with history

Synchronized with history

Strong and weak transitions

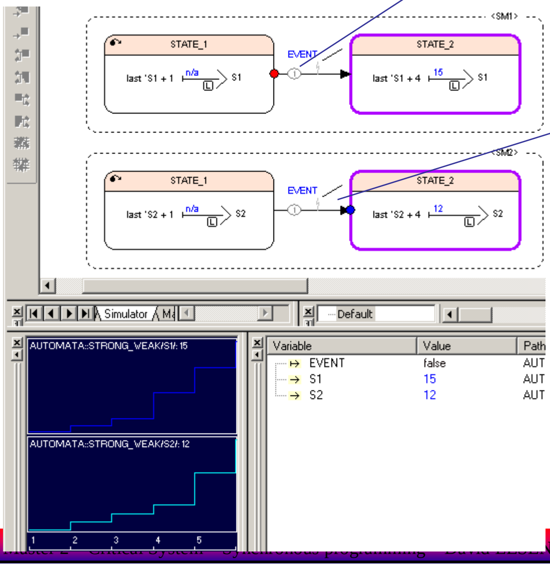
- Strong transition
  - The transition is triggered before the state execution
  - ➔ The guard can not depend on the current value of a data
- Weak transition

  (or “*weak delayed*”)
  - The state is executed before the transition triggering
  - ➔ The guard can depend on the current value of a data

Strong and weak transition

Strong transition

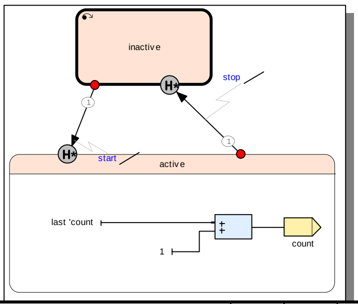
Weak transition



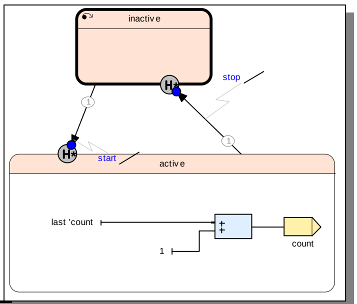
Variable	Value	Path
EVENT	false	AUT
S1	15	AUT
S2	12	AUT

Example (1/2)

Strong transition



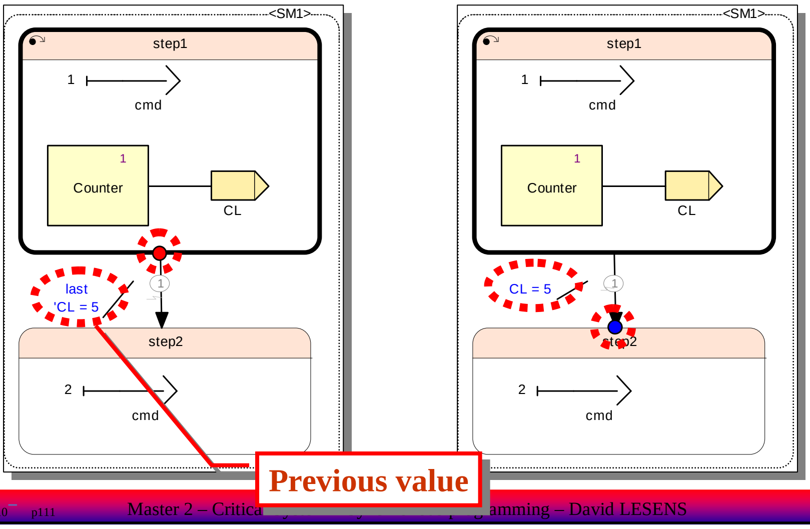
Weak transition



start				T							
stop								T			
count strong	0	0	0	1	2	3	4	4	4	4	4
count weak	0	0	0	0	1	2	3	4	4	4	4

Example (2/2)

The behaviours of the two following models are equivalent



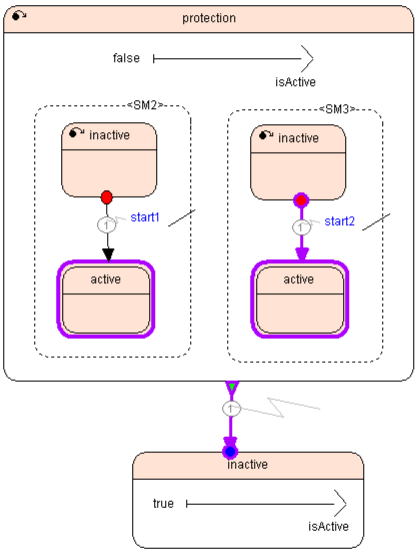
Previous value

Synchronized transition

- A synchronized transition
  - Has no guard
  - Is triggered as soon as all nested automata reach a final state

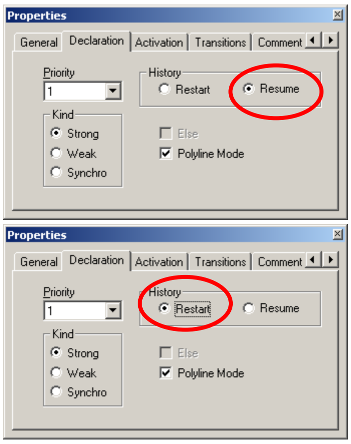
Example

- **Start1 received**
  - Still in protection state
- **Start2 received**
  - Final states reached
- **Transition inactive triggered**



Transition history

- Transition without history
  - The state resumes its execution
  - The memories are reset
- Transition with history
  - The state resumes its execution
  - The memories are not reset
- Two types of memories
  - PRE : local to the state
  - LAST : common to the node


Properties

General | Declaration | Activation | Transitions | Comment

Priority: 1

History: ○ Restart ● Resume

Kind: ● Strong ○ Weak ○ Synchro

□ Else

☑ Polyline Mode

Properties

General | Declaration | Activation | Transitions | Comment

Priority: 1

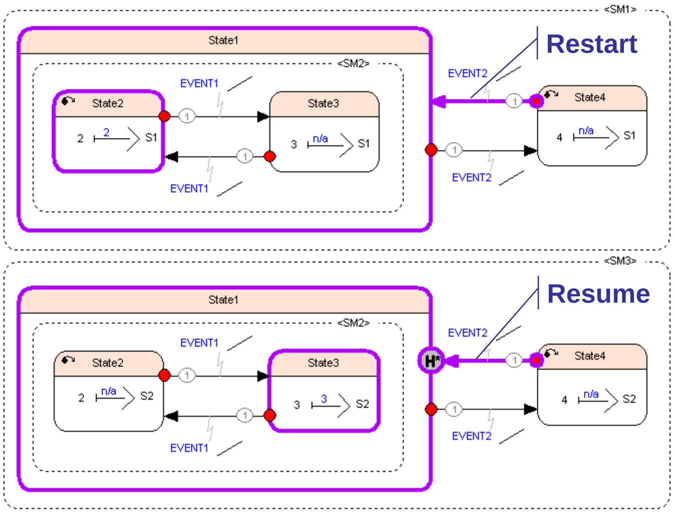
History: ● Restart ○ Resume

Kind: ● Strong ○ Weak ○ Synchro

□ Else

☑ Polyline Mode

Transition with history

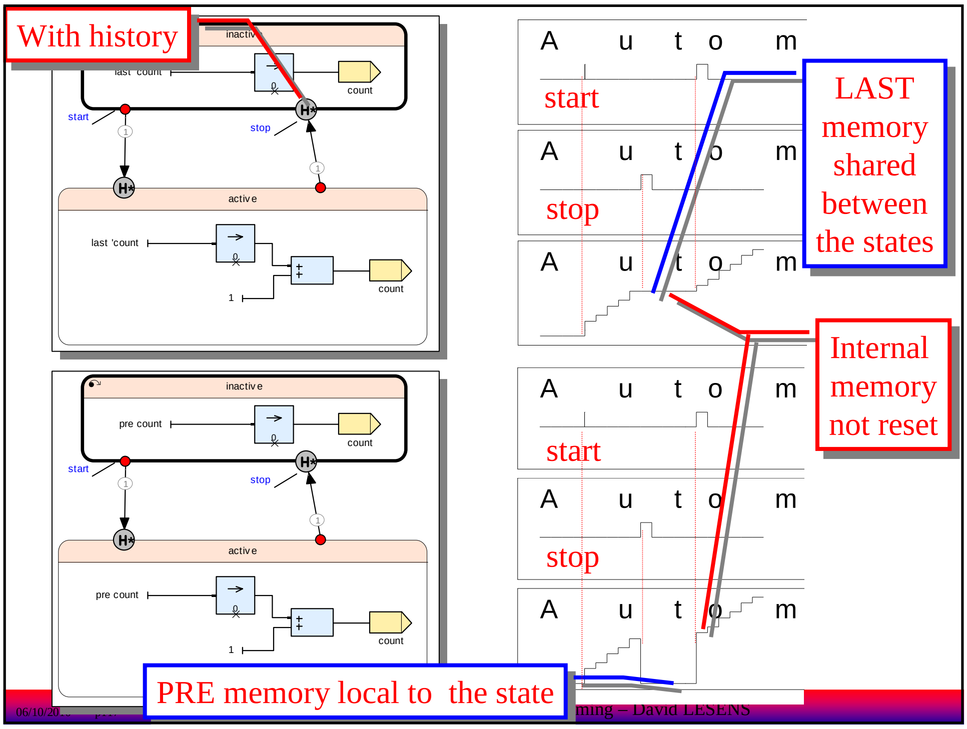


Shared memory

- Data flow point of view
  - Access to the last value of a flow in its scope
    - “pre *expression* ”
- Mode automata point of view
  - Access to values computed in other states
    - “last ‘x”

  (“x” is a named flow, not an expression

  ➔ utilization of ‘)



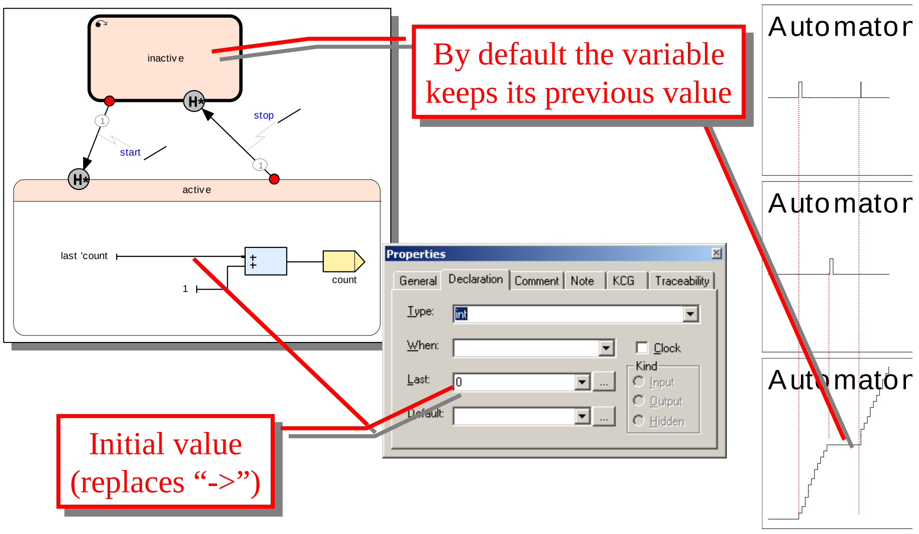
With history

LAST memory shared between the states

Internal memory not reset

PRE memory local to the state

Default actions in state



Type: int

When:

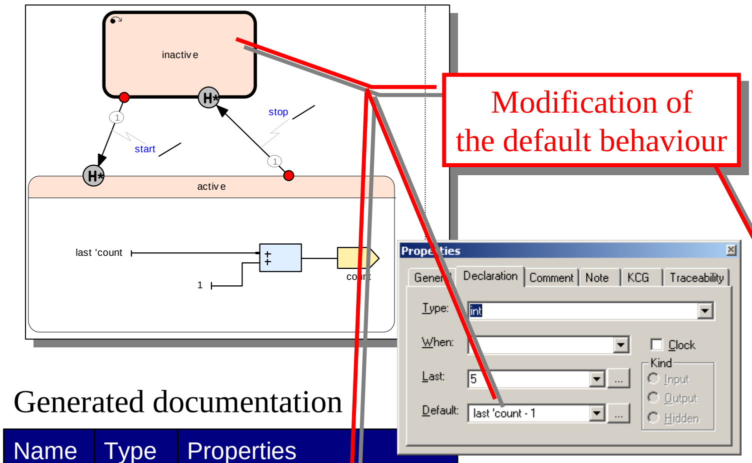
Last: 0

Default:

By default the variable keeps its previous value

Initial value (replaces “->”)

Modifying the default action



Properties

General | Declaration | Comment | Note | KCG | Traceability

Type: int

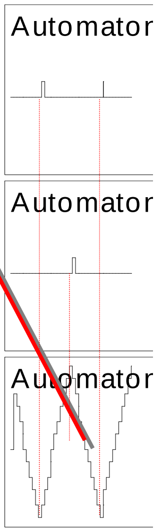
When:

☐ Clock

Kind
○ Input
○ Output
○ Hidden

Last: 5

Default: last 'count - 1

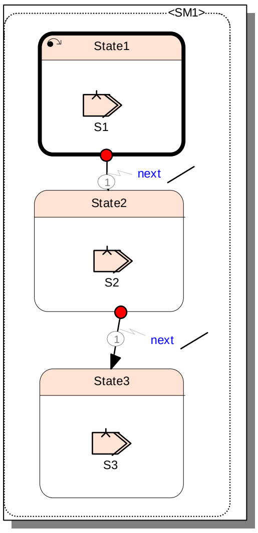


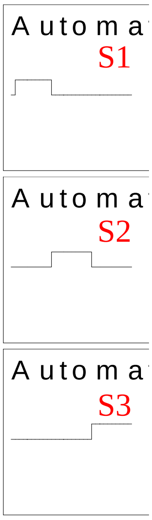
Generated documentation

Name	Type	Properties	
count	int	default	last 'count - 1
		last	5

Signals

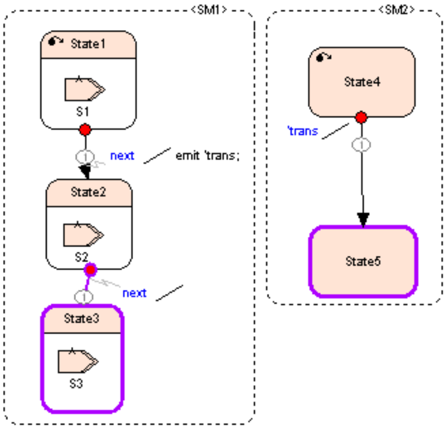
- A signal can be
  - Present ➔ true
  - Absent ➔ false
- A signal can not be
  - An input / output
- ≠ Boolean value
  - A Boolean value keeps its previous value then non updated in a state





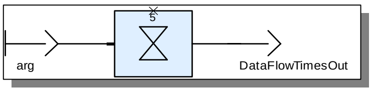
Composition and communication

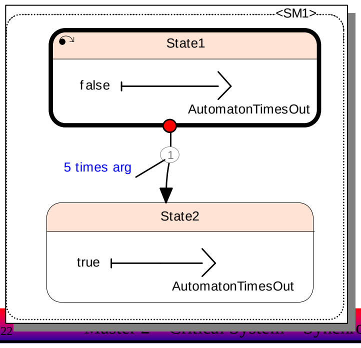
- A signal can be
  - Emitted in a state
  - Emitted on a transition
- A transition can be triggered by a signal

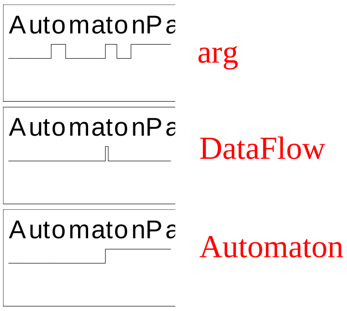


Factor

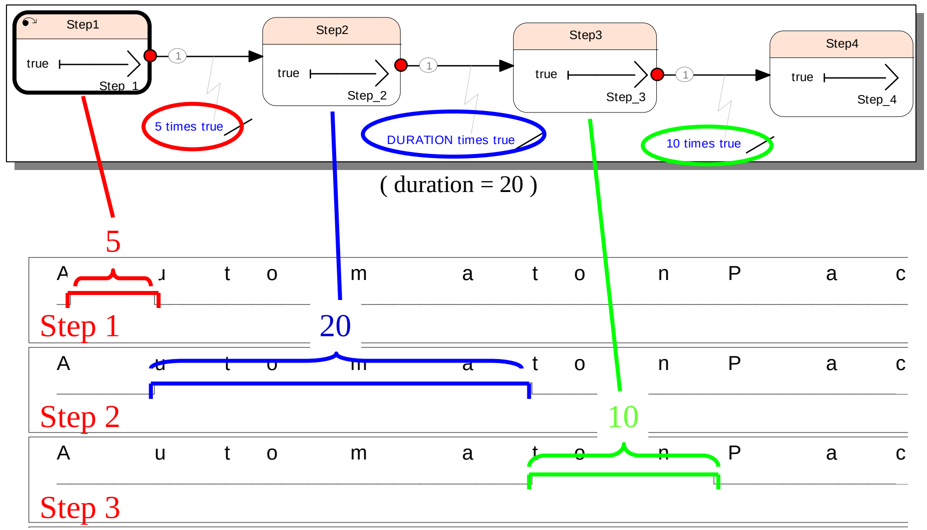
- A factor specifies on many time a condition must be true
  - In a data flow view
  - In a guard (automaton)



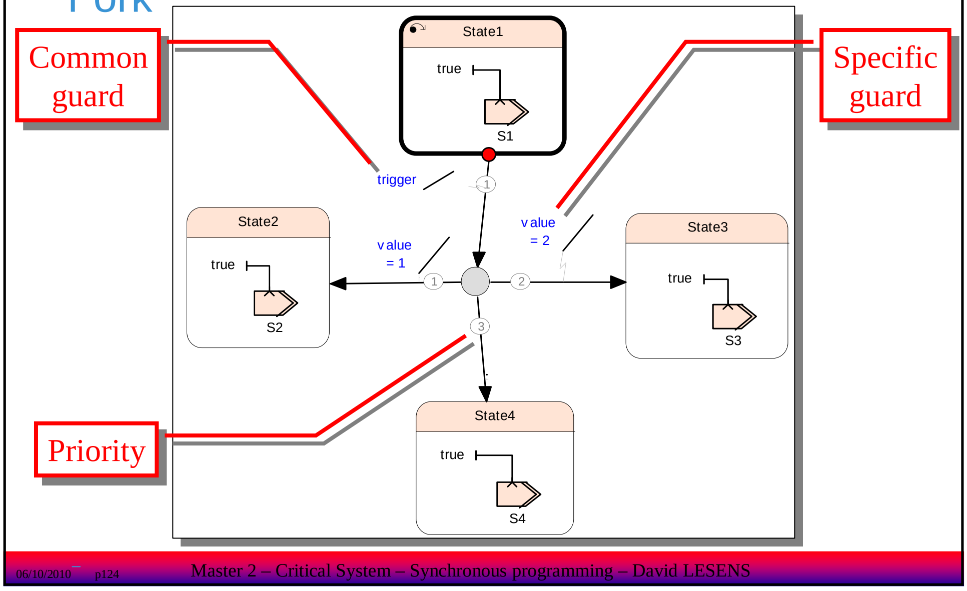




Time-out with factor



Fork

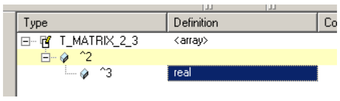


Overview

- Synchronous model ☞
- Introduction to the Scade language ☞
- Editing a Scade model ☞
- Activation conditions ☞
- Automata ☞
- Arrays ☞
- Iterations ☞
- Global flows: Sensors and probes ☞
- Genericity ☞

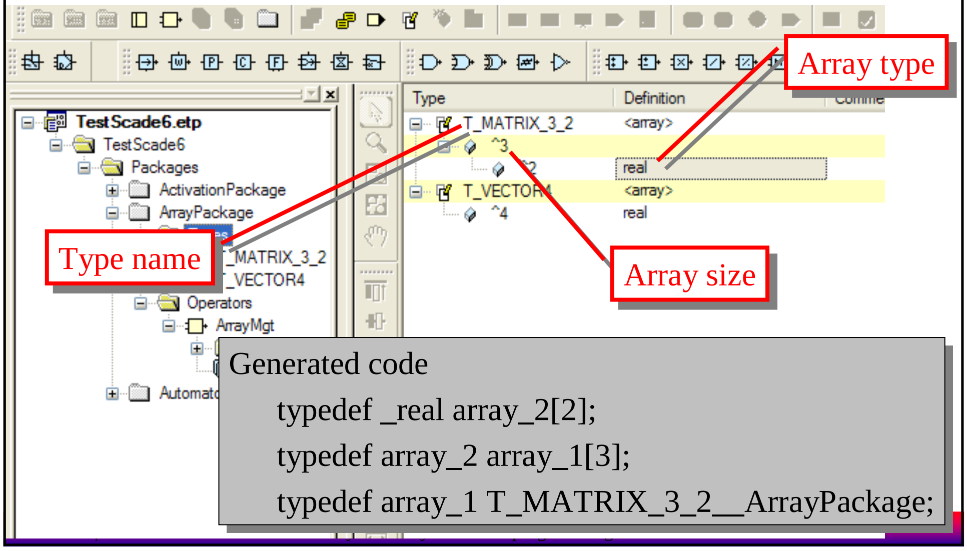
Arrays definition

- Restrictions
  - Static size
  - First element = index 0
- Definitions
  - type VECTOR = real ^ 4 ;
  - type MATRIX_2_3 = real ^ 3 ^ 2 ;
    - 2 lines, 3 columns
    - typedef real LINE_3[3];
    - typedef LINE_3 MATRIX_2_3 [2];



Type	Definition	Co
T_MATRIX_2_3	<array>	
^2		
^3	real	

Editing array types



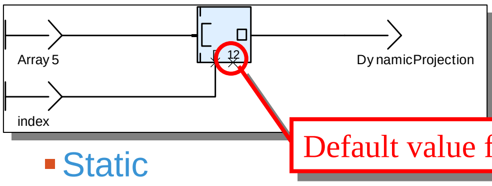
Generated code

```
typedef _real array_2[2];
typedef array_2 array_1[3];
typedef array_1 T_MATRIX_3_2__ArrayPackage;
```

Array access

Array5=[2,4,6,8,10], Index=3

- Dynamic

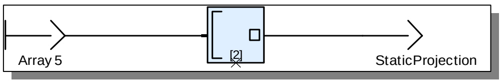


Index = 3 ➔ Output = 8

Index = 10 ➔ Output = 12

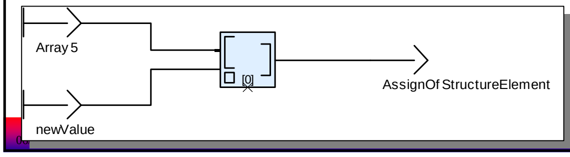
Default value for index out of range

- Static



Output = 6

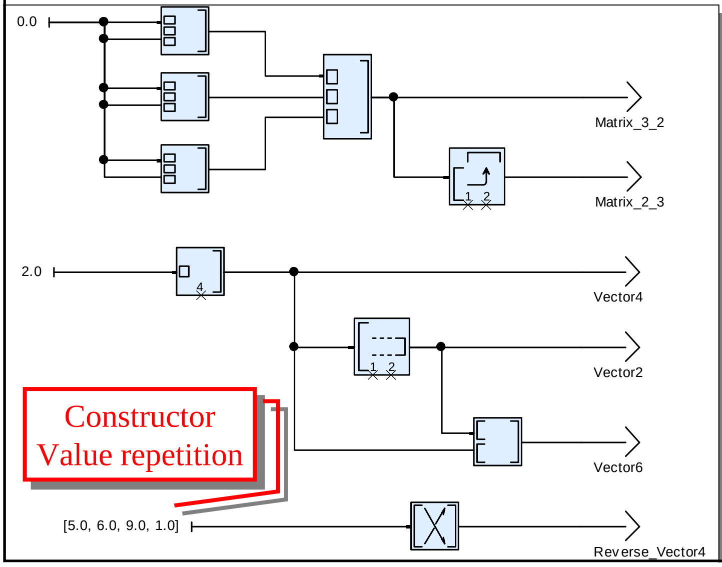
- Assignment



newValue = 3 ➔

Output = [3,4,6,8,10]

Some operators on arrays



Constructor
Value repetition

Data to Vector

Transpose of an Array

Scalar to Vector

Slice of a vector

Concatenation of Arrays

Reverse of a Vector

Overview

- Synchronous model
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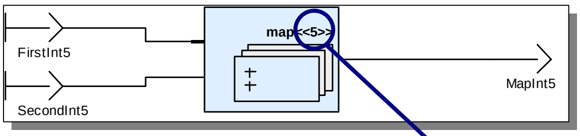
Iterations

- Equivalent to “for” in C

Map / Mapi / Mapw / Mapiw
Fold / Foldi / Foldi / Foldiw

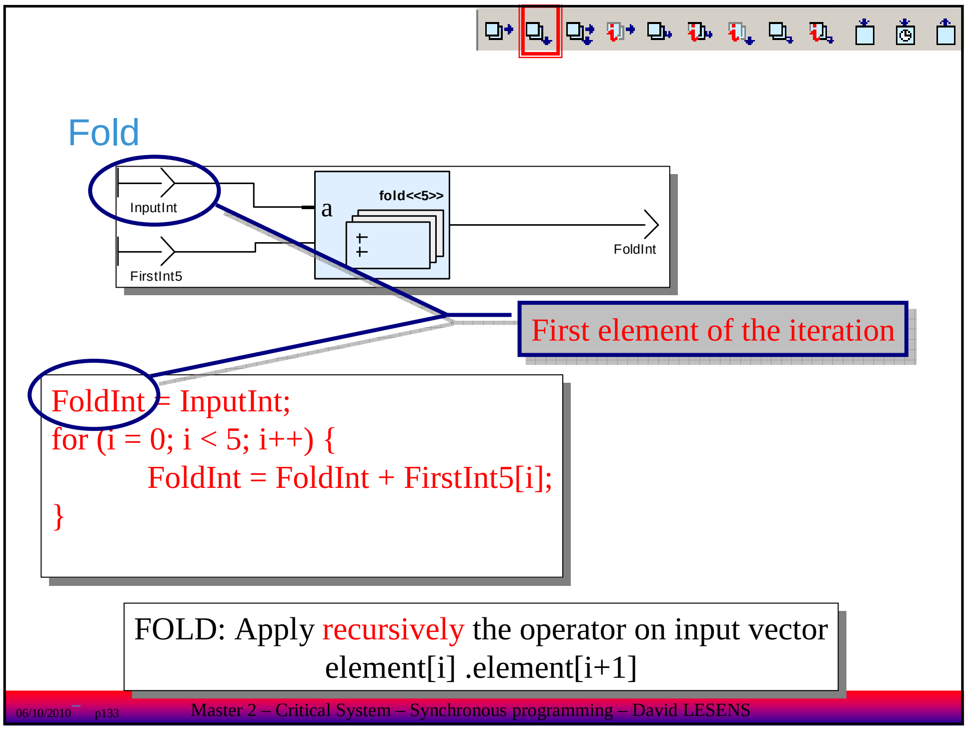
Map



Size of the input vector

```
for (i = 0; i < 5; i++) {
        MapInt5[i] = FirstInt5[i] + SecondInt5[i];
}
```

MAP: Apply the operator successively on each element of the input vector(s) element[i] .element’[i]

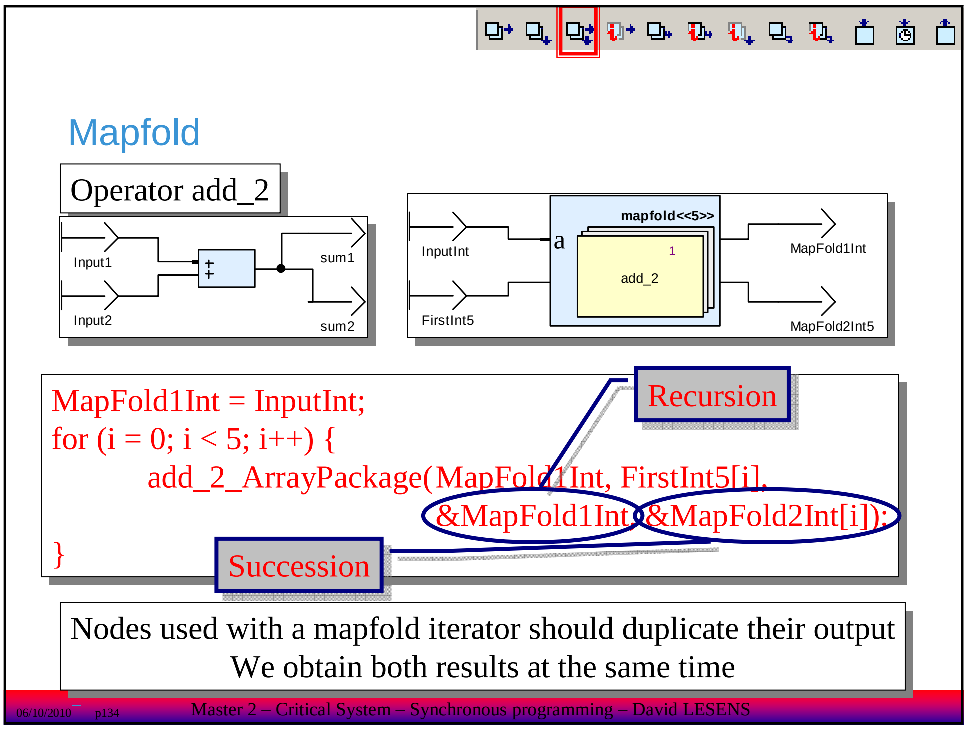


Fold

First element of the iteration

```
FoldInt = InputInt;
for (i = 0; i < 5; i++) {
        FoldInt = FoldInt + FirstInt5[i];
}
```

FOLD: Apply recursively the operator on input vector element[i] .element[i+1]



Mapfold

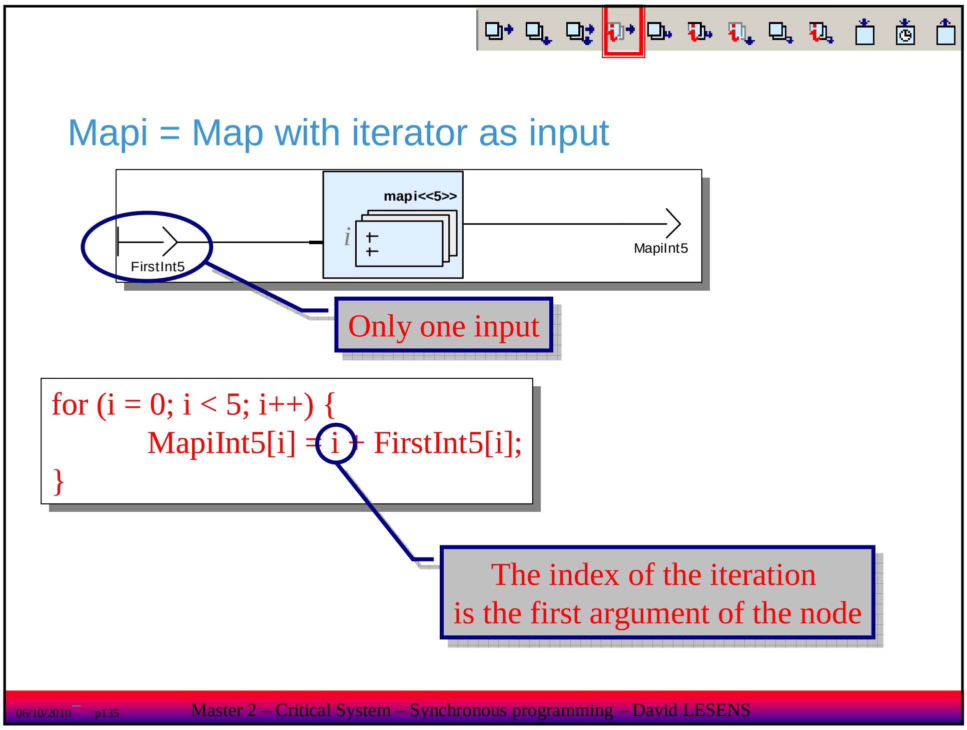
Operator add_2

```
MapFold1Int = InputInt;
for (i = 0; i < 5; i++) {
        add_2_ArrayPackage(MapFold1Int, FirstInt5[i],
                &MapFold1Int,&MapFold2Int[i]);
}
```

Recursion

Succession

Nodes used with a mapfold iterator should duplicate their output
We obtain both results at the same time

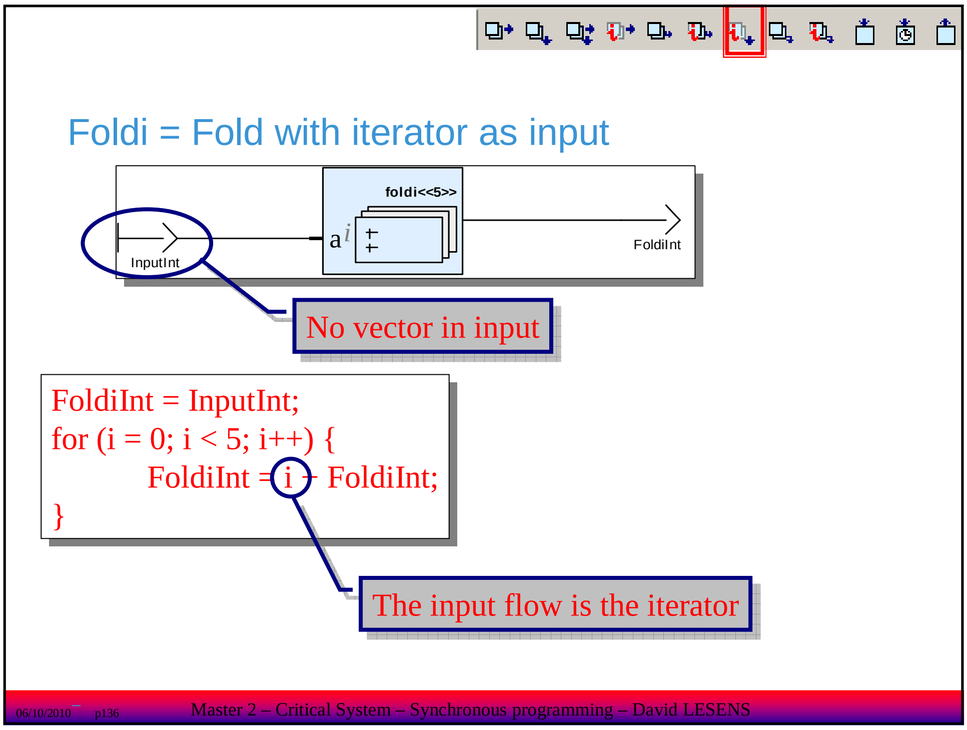


Mapi = Map with iterator as input

Only one input

```
for (i = 0; i < 5; i++) {
        MapiInt5[i] = i + FirstInt5[i];
}
```

The index of the iteration
is the first argument of the node



Foldi = Fold with iterator as input

No vector in input

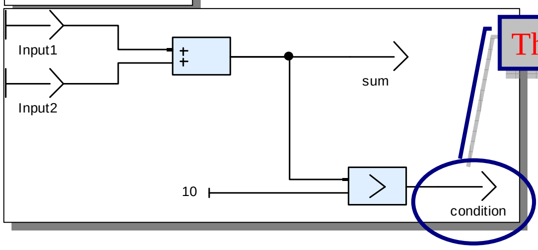
```
FoldiInt = InputInt;
for (i = 0; i < 5; i++) {
        FoldiInt = i + FoldiInt;
}
```

The input flow is the iterator

Mapw / Foldw = Partial operators

- Capability to stop an iteration on a Boolean condition computed by the operator

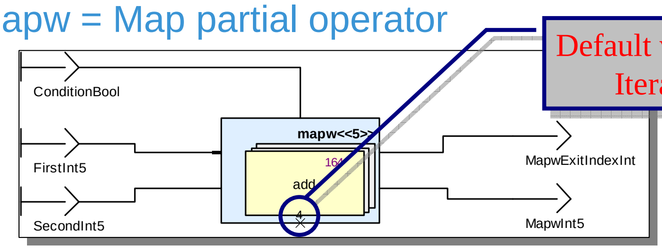
Operator add



The iteration can be stopped

As soon as the condition is false, the iteration is topped

Mapw = Map partial operator



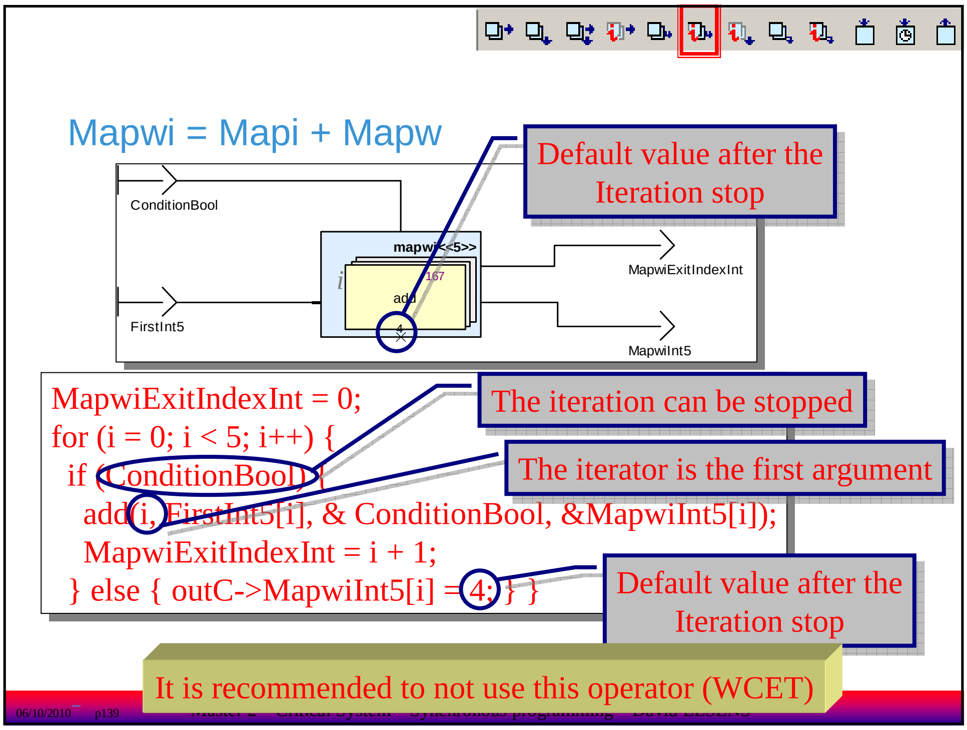
Default value after the Iteration stop

```
MapwExitIndexInt = 0;
for (i = 0; i < 5; i++) {
  if (ConditionBool) {
    add(FirstInt5[i], SecondInt5[i], &ConditionBool, &MapwInt5[i]);
    MapwExitIndexInt = i + 1;
  } else { MapwInt5[i] = 4; } }
```

The iteration can be stopped

Default value after the Iteration stop

It is recommended to not use this operator (WCET)



Mapwi = Mapi + Mapw

Default value after the Iteration stop

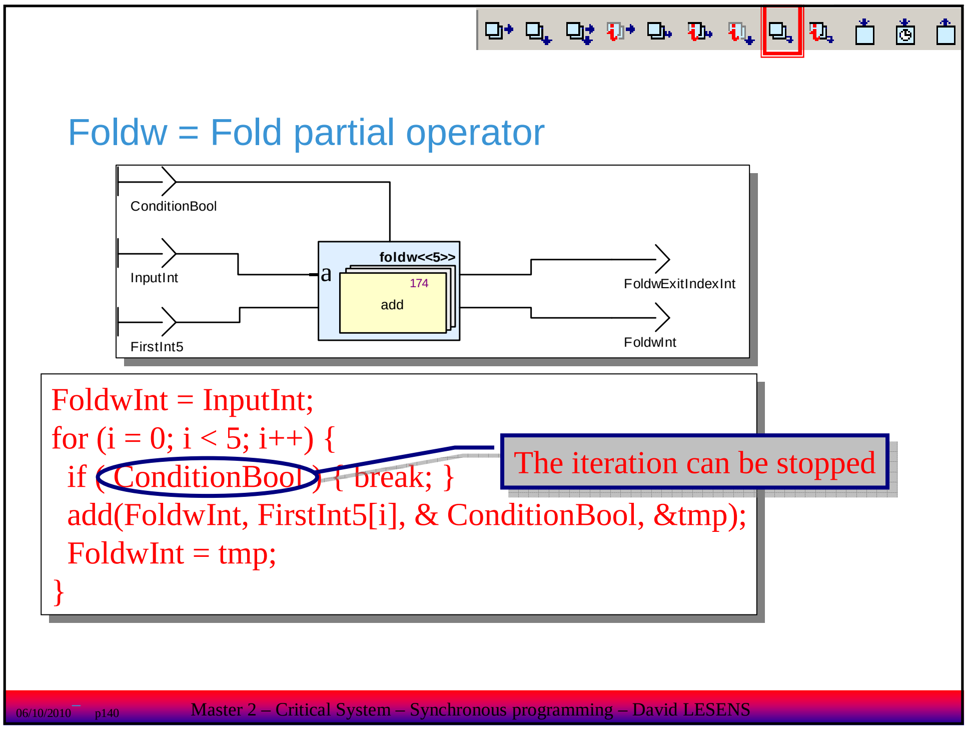
```
MapwiExitIndexInt = 0;
for (i = 0; i < 5; i++) {
  if (ConditionBool) {
    add(i, FirstInt5[i], & ConditionBool, &MapwiInt5[i]);
    MapwiExitIndexInt = i + 1;
  } else { outC->MapwiInt5[i] = 4; } }
```

The iteration can be stopped

The iterator is the first argument

Default value after the Iteration stop

It is recommended to not use this operator (WCET)

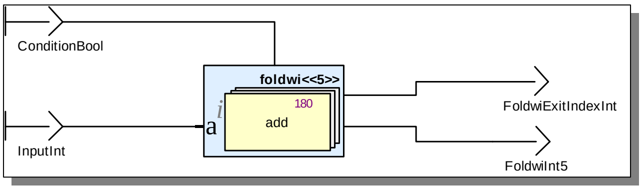


Foldw = Fold partial operator

```
FoldwInt = InputInt;
for (i = 0; i < 5; i++) {
  if (ConditionBool ) { break; }
  add(FoldwInt, FirstInt5[i], & ConditionBool, &tmp);
  FoldwInt = tmp;
}
```

The iteration can be stopped

Foldwi = Foldi + Foldw



```
FoldwiInt5 = InputInt; tmp = ConditionBool;
for (i = 0; i < 5; i++) {
  if ( ConditionBool ) { break; }
  add(i, FoldwiInt5, & ConditionBool, &tmp);
  FoldwiInt5 = tmp;
}
FoldwiExitIndexInt = i;
```

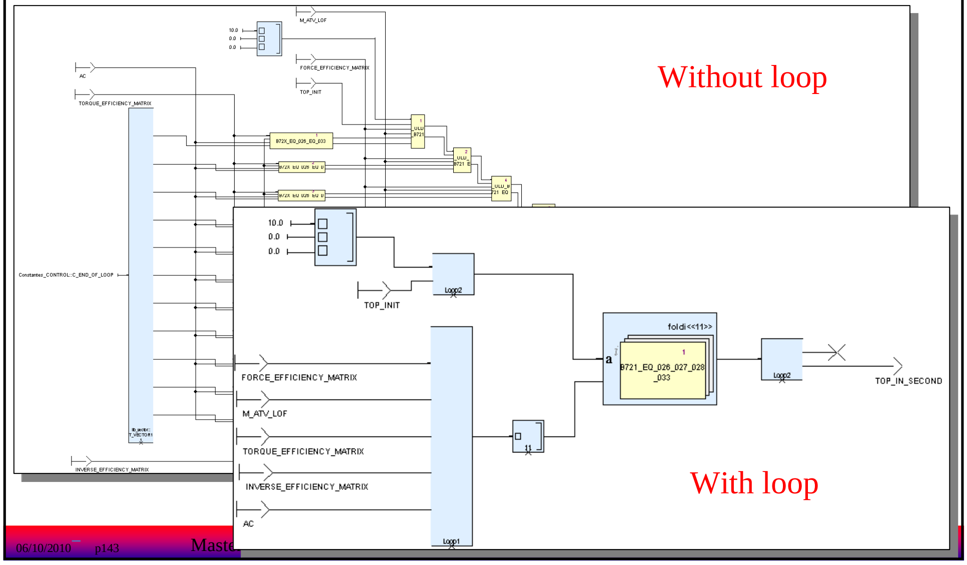
The iteration can be stopped

The input flow is the iterator

Iteration summary

- Map = Successive application
- Fold = Recursive application
- Mapfold = Map + Fold
- Mapi = Map with iterator as input
- Foldi = Fold with iterator as input
- Mapw = Map partial operator
- Mapwi = Mapi + Mapw
- Foldw = Fold partial operator
- Foldwi = Foldi + Foldw

Example 1

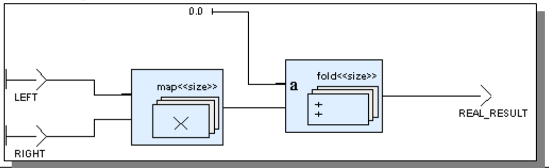


Without loop

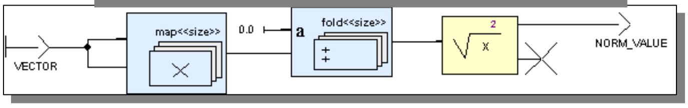
With loop

Example 2: cross product

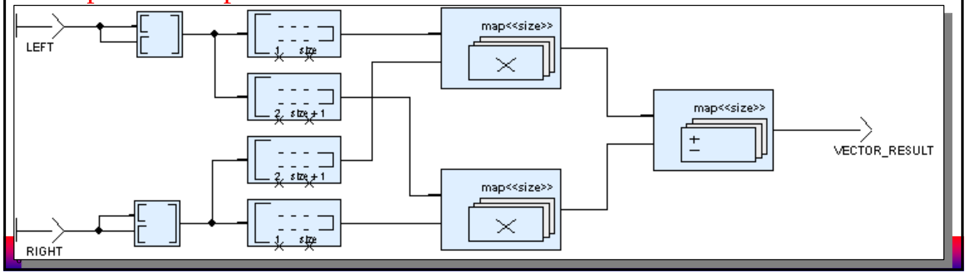
Compute scalar product



Compute vector norm



Compute cross product



Overview

- Synchronous model
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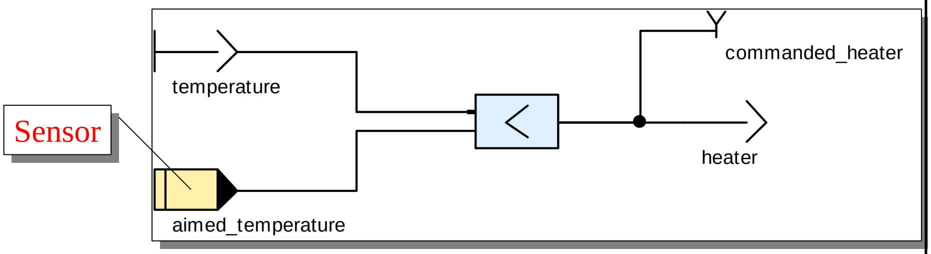
- Genericity

Sensors

- Sensor: Global system input

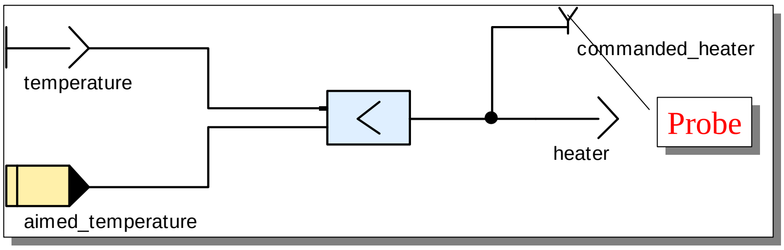
Input temperature
Output heater



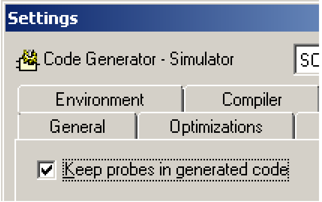
extern _int aimed_temperature__ProbePackage;

Probes

- Probe: Global system output



```
typedef struct {/* context */
_bool heater; /* outputs */
_bool commanded_heater; /* probes */
} C_controller__ProbePackage;
```



☑ Keep probes in generated code

Overview

- Synchronous model ☞
- Introduction to the Scade language ☞
- Editing a Scade model ☞
- Activation conditions ☞
- Automata ☞
- Arrays ☞
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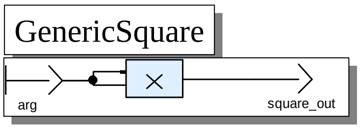
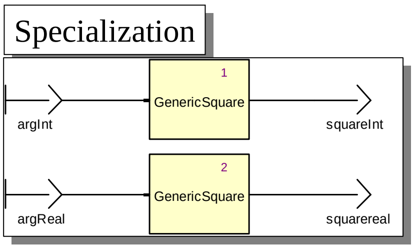
- Genericity ☞

Generic operator definition

GenericSquare



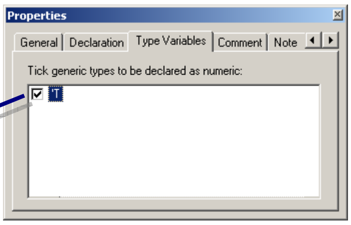
Specialization



	Name	Type
Input	**arg**	**'T**
Output	**square_out**	**'T**

Name	Generic Type
'T	**numeric**

Definition of a generic numeric type



Tick generic types to be declared as numeric:

☑ 'T

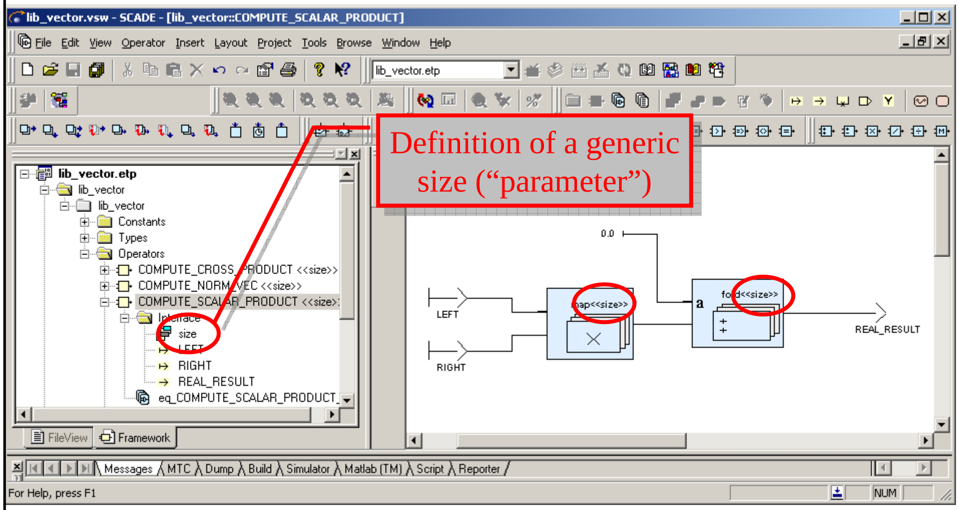
Generic operator instantiation

```
int GenericSquare_int ( int arg ) {
          int square_out;
          square_out = arg * arg;
          return square_out;
}
```

```
real GenericSquare_real ( real arg ) {
          real square_out;
          square_out = arg * arg;
          return square_out;
}
```

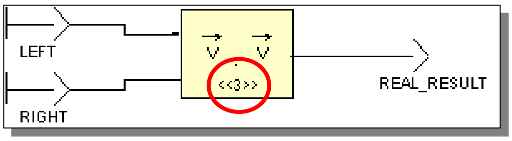
```
void Specialization(    int argInt; real argReal;
                        int squareInt; real squarereal; ) {
*squareReal = GenericSquare_real ( argReal );
*squareInt =  GenericSquare_int ( argInt );
}
```

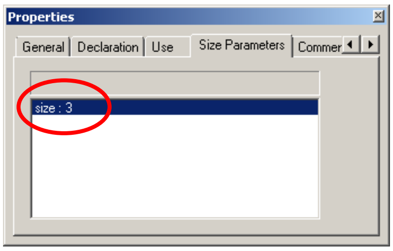
Definition of parameters


lib_vector.vsw - SCADE - [lib_vector::COMPUTE_SCALAR_PRODUCT]
File Edit View Operator Insert Layout Project Tools Browse Window Help
lib_vector.etp
lib_vector
lib_vector
Constants
Types
Operators
COMPUTE_CROSS_PRODUCT <<size>>
COMPUTE_NORM_VEC <<size>>
COMPUTE_SCALAR_PRODUCT <<size>>
Interface
size
LEFT
RIGHT
REAL_RESULT
eq_COMPUTE_SCALAR_PRODUCT_
FileView
Framework
0.0
LEFT
RIGHT
map<<size>>
fold<<size>>
a
REAL_RESULT
Messages MTC Dump Build Simulator Matlab (TM) Script Reporter
For Help, press F1
NUM

Definition of a generic size (“parameter”)

Parameter instantiation





size : 3

```
REAL_RESULT = 0.0;
for (i = 0; i < 3; i++) {
   REAL_RESULT = REAL_RESULT + (*LEFT)[i] * (*RIGHT)[i];
}
return REAL_RESULT;
```

Overview

- Critical real-time embedded software ☞
- Principles of the approach ☞
  - Introduction ☞
  - Formal semantics ☞
- SCADE ☞
- Model validation ☞

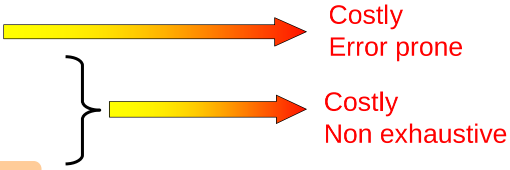
Software validation

Correct software

- No runtime errors
- Satisfaction of real time constraints
- Compliance with the expected results

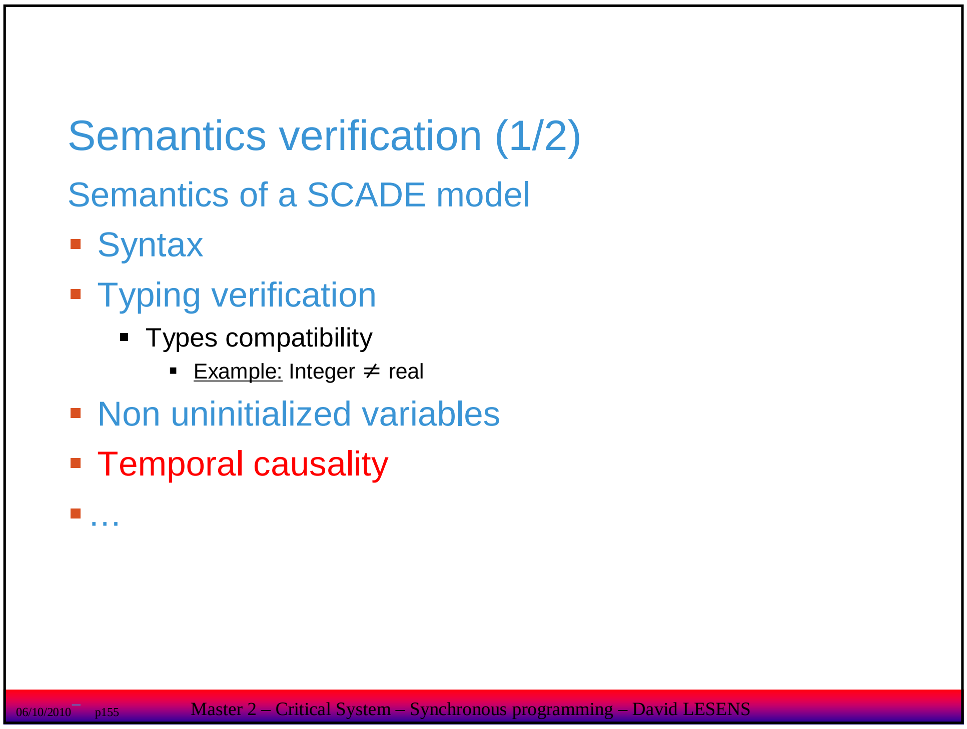
Solutions

- Manual review
- Dynamic testing
  - A code level
  - At model level
- Semantics checking
- Abstract interpretation
- Formal proof



Costly
Error prone

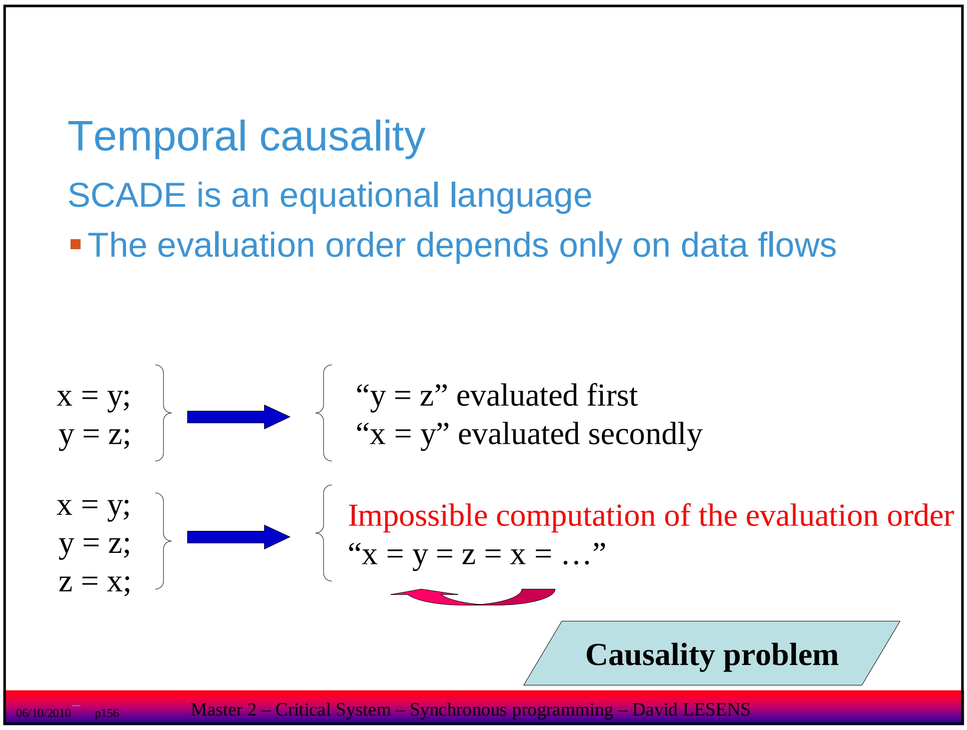
Costly
Non exhaustive



Semantics verification (1/2)

Semantics of a SCADE model

- Syntax
- Typing verification
  - Types compatibility
    - Example: Integer ≠ real
- Non uninitialized variables
- Temporal causality
- …



Temporal causality

SCADE is an equational language

- The evaluation order depends only on data flows

x = y;
y = z;

“y = z” evaluated first
“x = y” evaluated secondly

x = y;
y = z;
z = x;

Impossible computation of the evaluation order
“x = y = z = x = …”

Causality problem

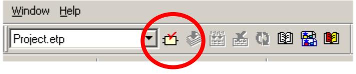
Semantics verification (2/2)

A SCADE model with a correct semantics is:

- Complete
- Consistent
- Implementable

➔ The good properties of a specification

➔ “Semantics check” to be systematically performed



But does the software behave as expected?

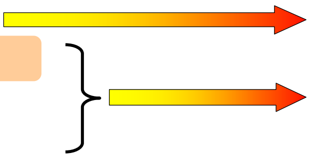
Software validation

Correct software

- No runtime errors
- Satisfaction of real time constraints
- Compliance with the expected results

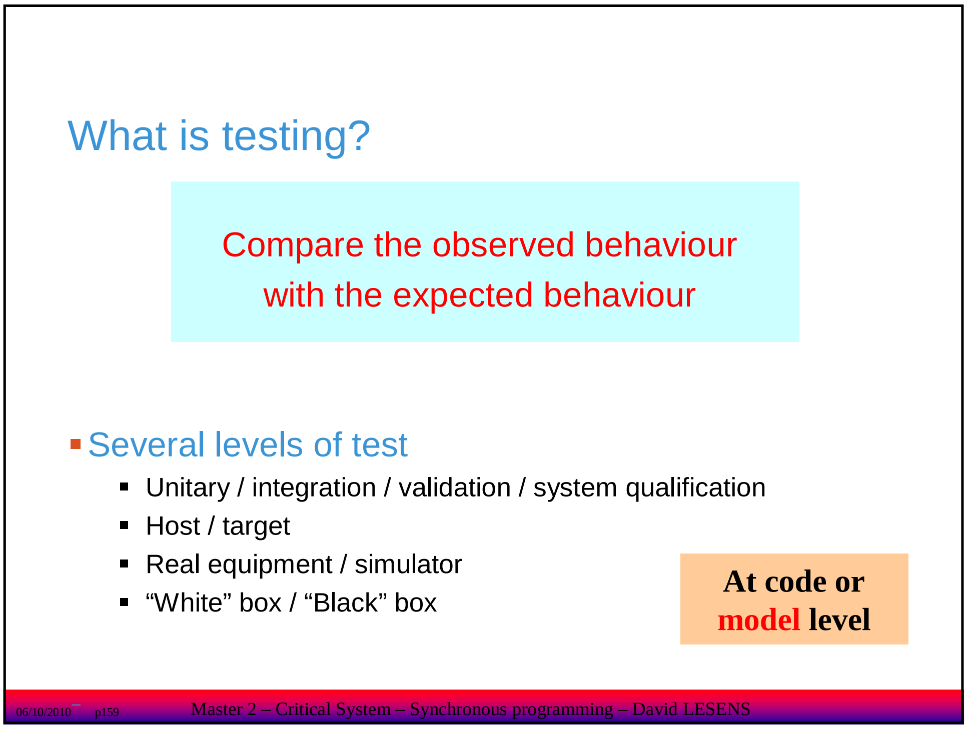
Solutions

- Manual review
- Dynamic testing
  - A code level
  - At model level
- Semantics checking
- Abstract interpretation
- Formal proof



Costly
Error prone

Costly
Non exhaustive

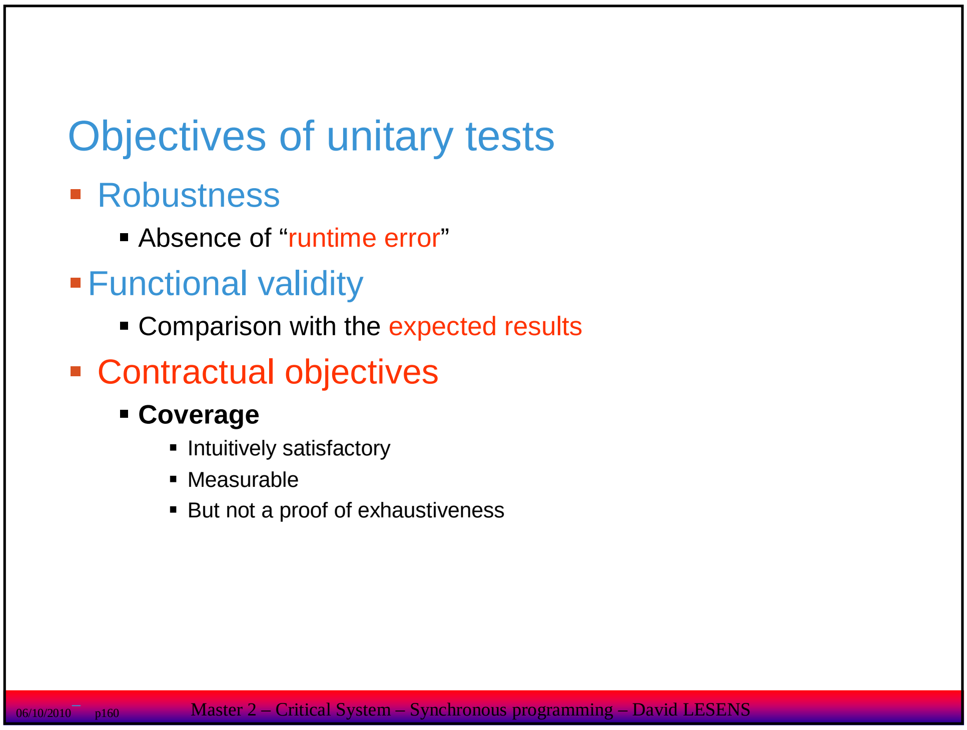


What is testing?

Compare the observed behaviour with the expected behaviour

- Several levels of test
  - Unitary / integration / validation / system qualification
  - Host / target
  - Real equipment / simulator
  - “White” box / “Black” box

At code or model level



Objectives of unitary tests

- Robustness
  - Absence of “runtime error”
- Functional validity
  - Comparison with the expected results
- Contractual objectives
  - **Coverage**
    - Intuitively satisfactory
    - Measurable
    - But not a proof of exhaustiveness

Unitary tests: Coverage

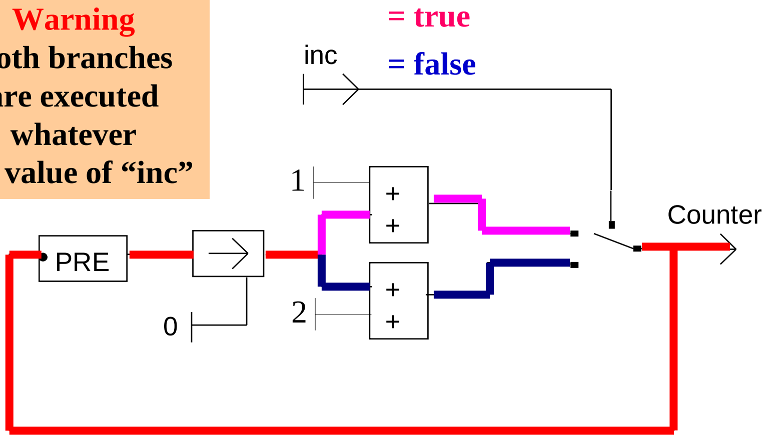
```
Procedure f(x : in real; y: in real; z : out real)
        if (x > 1.0) or (x < -1.0) then
                z := y/x;
        else
                z := y;
        if z < 2.0 then
                z = 2.0;
```

Coverage

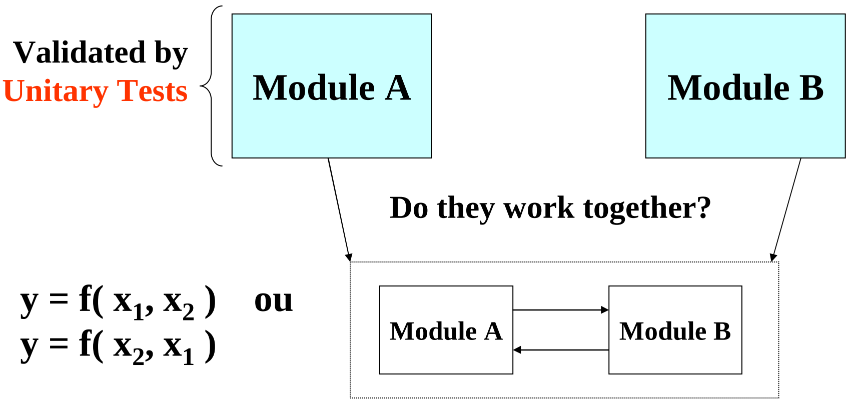
➢ **branch**	**(x=2.0, y=6.0), (x=-1.0,y=1.0)**
➢ **decision**	**+ (x=-2, y=3.0)**
➢ **path**	**+ (x=2.0, y=1.0), (x=0.5,y=2.0)**

Coverage of a SCADE model

Warning
Both branches are executed whatever the value of "inc"



Integration test

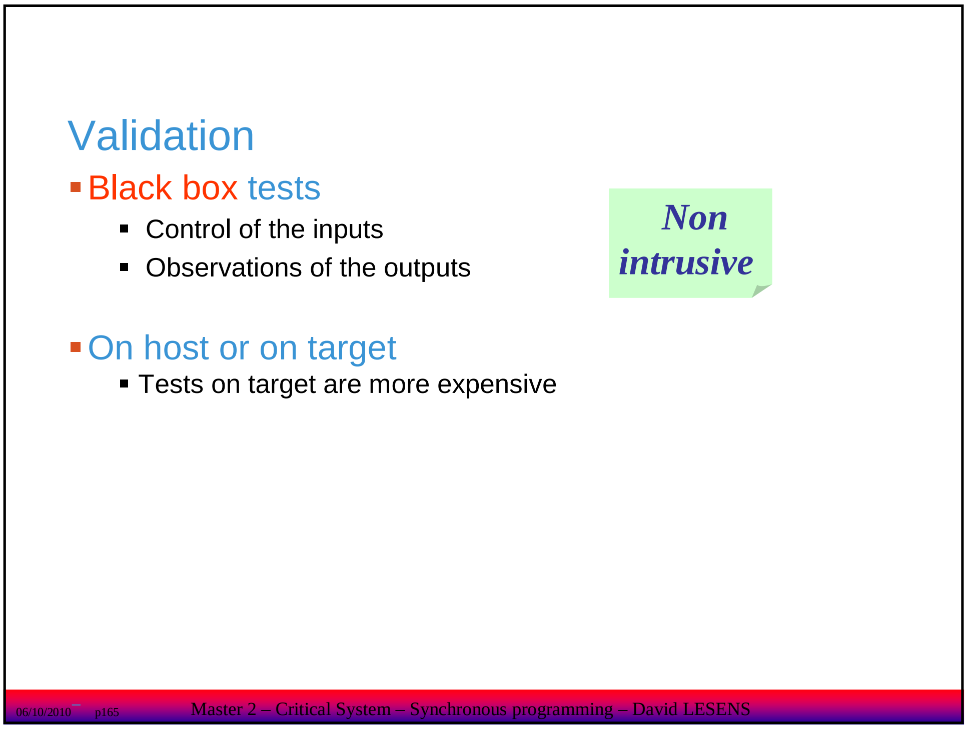


$y = f(x_1, x_2)$ **ou**
$y = f(x_2, x_1)$

Validation of interfaces in white box

Limit of the white box approach

- The presence of a spy may modify the real time behaviour
- What happens if the debugger / simulator has … a bug?

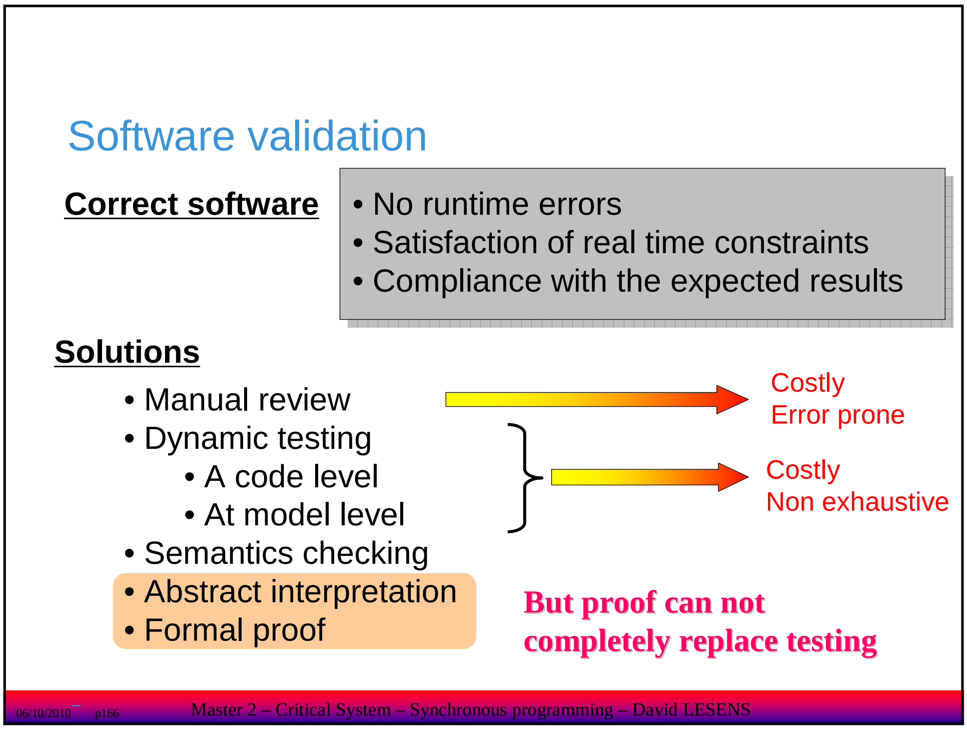


Validation

- Black box tests
  - Control of the inputs
  - Observations of the outputs

Non intrusive

- On host or on target
  - Tests on target are more expensive



Software validation

Correct software

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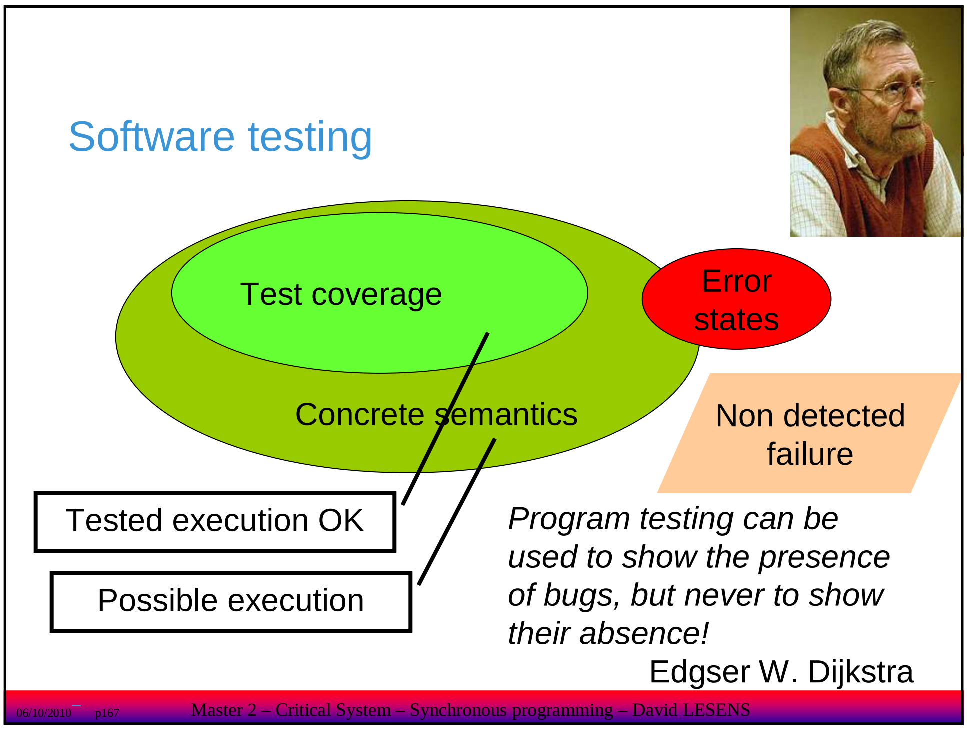
Solutions

- Manual review
- Dynamic testing
  - A code level
  - At model level
- Semantics checking
- Abstract interpretation
- Formal proof

Manual review → Costly, Error prone

Dynamic testing (A code level, At model level) → Costly, Non exhaustive

But proof can not completely replace testing



Software testing

Test coverage

Concrete semantics

Error states

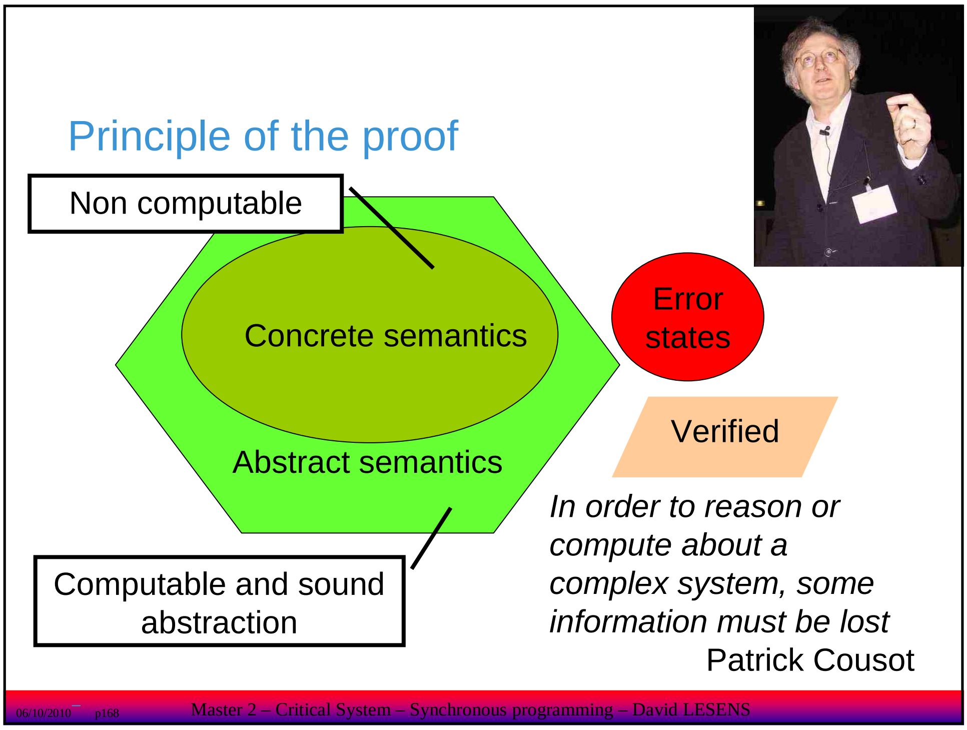
Non detected failure

Tested execution OK

Possible execution

Program testing can be used to show the presence of bugs, but never to show their absence!

Edgser W. Dijkstra



Principle of the proof

Non computable

Concrete semantics

Abstract semantics

Error states

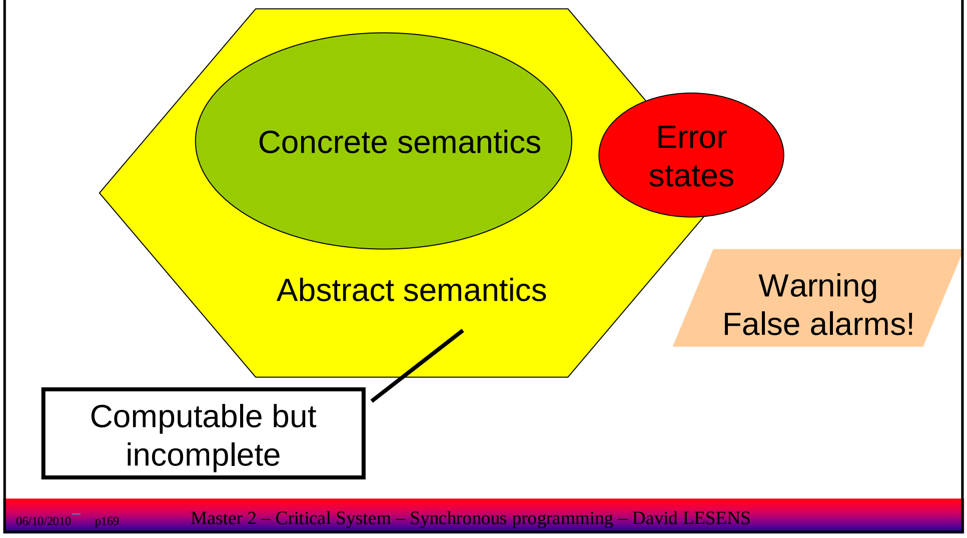
Verified

Computable and sound abstraction

In order to reason or compute about a complex system, some information must be lost

Patrick Cousot

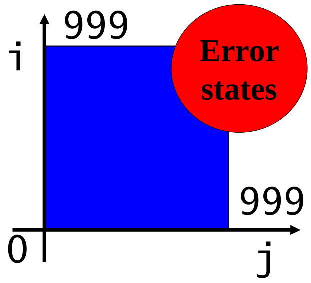
Proof limitation



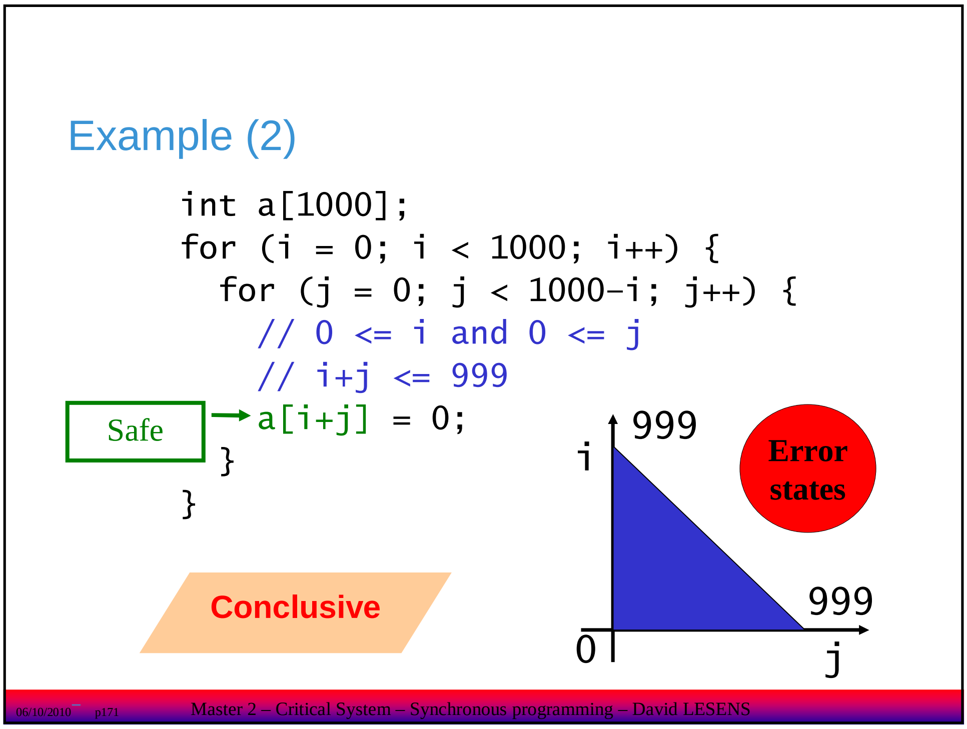
Example (1)

```
int a[1000];
for (i = 0; i < 1000; i++) {
  for (j = 0; j < 1000-i; j++) {
    // 0 <= i <= 999
    // 0 <= j <= 999
    a[i+j] = 0;
  }
}
```

Warning

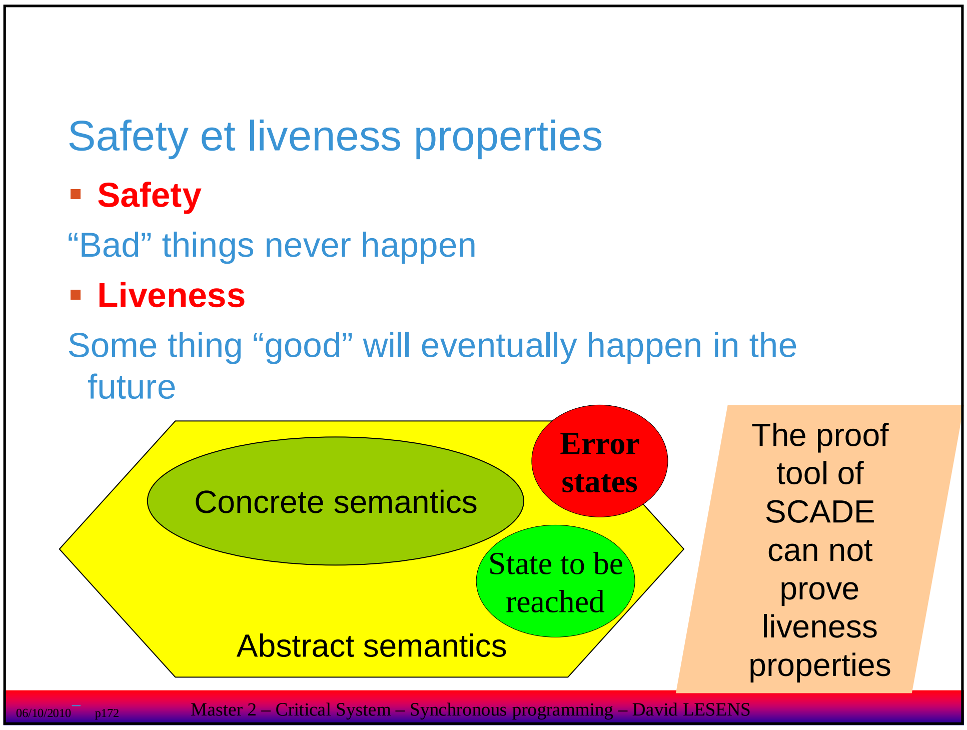


Non conclusive



Example (2)

```
int a[1000];
for (i = 0; i < 1000; i++) {
  for (j = 0; j < 1000-i; j++) {
    // 0 <= i and 0 <= j
    // i+j <= 999
    a[i+j] = 0;
  }
}
```



Safety et liveness properties

- **Safety**

"Bad" things never happen

- **Liveness**

Some thing "good" will eventually happen in the future

The proof tool of SCADE can not prove liveness properties

Interest of the liveness properties

- “Liveness” property / “timed” property
  - Example: if an error is detected, the software shall raise an alarm toward the user
    - Liveness: the alarm will mandatorily be raised (one day or another)

But when?

➔ Not *acceptable for a critical real time piece of software*

❖ Timed property: the alarm will mandatorily be raised 1 second after the failure occurence

➔ **Safety property**

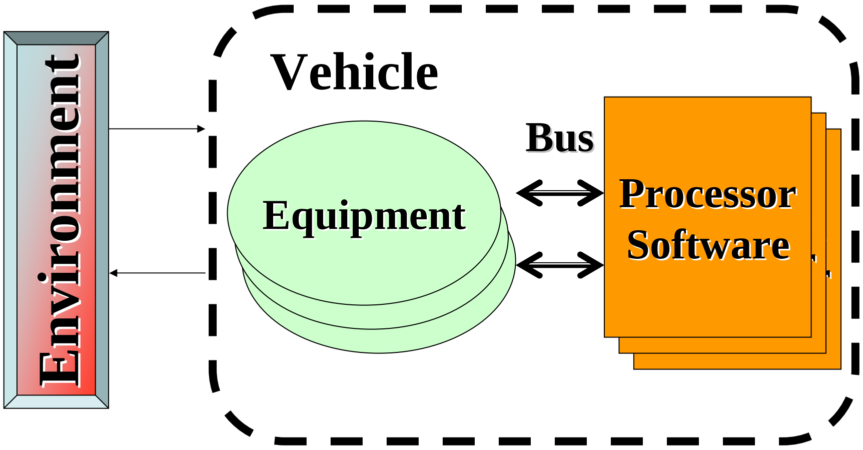
Formal proof

- “Mathematical” exhaustive demonstration that a piece of software/code satisfied a property

➔ Rarely the case!

A piece software generally satisfies a property only in a correct environment

The software is part of a complex system



Formal proof principles

- Software under validation
- Properties to be satisfied
- Software environment

(□ correct environment) ∧ software ⇒ properties

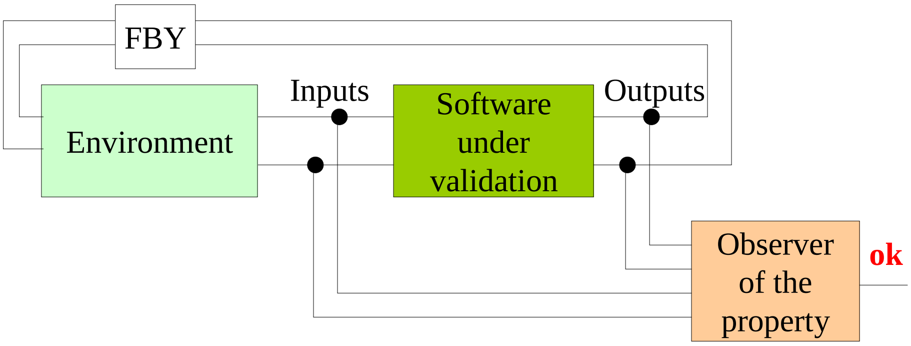
- Environment in open or close loop

Expression of properties

Notion of observer

- An observer is a software observing the software under validation and returning “true” as long as the property is satisfied
  - Observation of the software inputs
  - Observation of the software outputs
- Idem for the environment properties

Observers in SCADE



➔ Use for testing (oracle)
➔ Use by SCADE proof tool

Non deterministic environment (1/2)

The software environment is generally not fully deterministic

- Human action
- Failure
- …

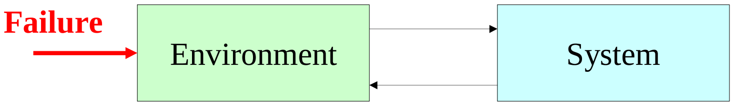
➔ Non deterministic environment

But SCADE is a deterministic language!

Non deterministic environment (2/2)

The non determinism is modelled by an additional input

Example: Failure occurrence



Assertion

An assertion allows to restrict an environment “too much” non deterministic

Example:

- Input “gf” models a gyroscope failure
- Input “tf” models a thruster failureune panne d’une tuyère
  - ➔ To develop a “one fault tolerant” system

Hypothesis: assert #(gf, tf)

The End