Cours MALG & MOVEX

Overview of the course

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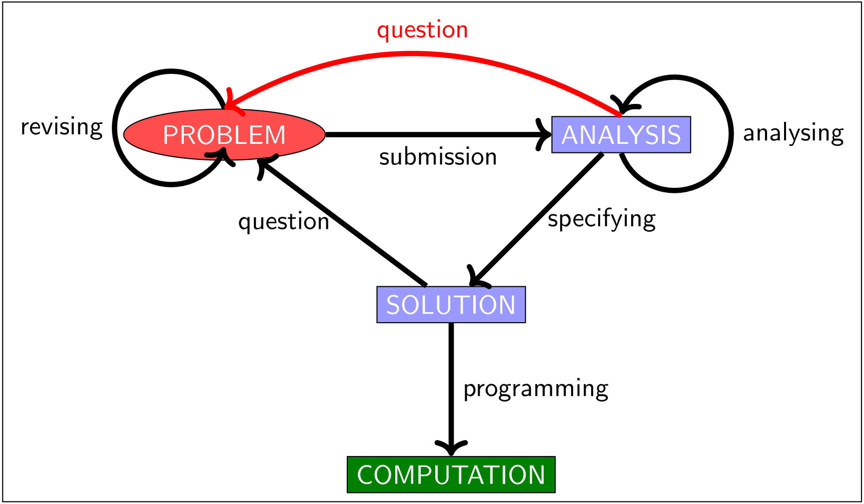
Plan

Sommaire

Problem versus Solution



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- *bug1.c* functional bug
- *bug2.c* stupid bug of writing a code
- bug5.c prints *Element 10 found at index 5*
- bug6.c prints *Floating point exception : 8*

Listing 1 – Bug bug0

```c
#include <stdio.h>
#include <stdlib.h>
#include <time.h>

int main() {
    int x, y;
    // Seed the random number generator with the current time
    srand(time(NULL));
    // Generate a random number between 1 and 100
    x = rand() % 100 + 1;
    // Perform some calculations
    y = x / (100 - x);
    printf("Result: %d\n", y);
    return 0;
}
```

bug00.c

Listing 2 – Bug bug00

```
// Heisenbug
#include <stdio.h>
#include <stdlib.h>
#include <time.h>



int main() {
  int x, y,i=0;

    for (i = 0; i <= 100000; i++) {
    // Seed the random number generator with the current time
    srand(time(NULL));

    // Generate a random number between 1 and 100
    x = rand() % 100 + 1;
        printf("Result: x= %d\n",x);
    // Perform some calculations
    y = x / (100 - x);

    printf("Result: i=%d %d\n",i, y);
    }

    return 0;
}
```

bug000.c

Listing 3 – Bug bug000

```c
// Heisenbug
#include <stdio.h>
#include <stdlib.h>
#include <time.h>



int main() {
  int x, y, i=0;

    for (i = 0; i <= 100; i++) {
    // Seed the random number generator with the current time
    srand(time(NULL)+i);

    // Generate a random number between 1 and 100
    x = rand() % 100 + 1;
        printf("Result: x= %d\n",x);
    // Perform some calculations
    y = x / (100 - x);

    printf("Result: i=%d %d\n",i, y);
    }

    return 0;
}
```

bug1.c

Listing 4 – Bug bug1

```
#include <stdio.h>

int main() {
    int numbers[5] = {1, 2, 3, 4, 5};
    int sum = 0;

    // Attempt to calculate the sum of numbers in the array
    for (int i = 0; i <= 5; i++) {
        sum += numbers[i];
    }

    printf("Sum: %d\n", sum);
    sum = numbers[7];
    printf("Sum: %d\n", sum);

    return 0;
}
```

bug2.c

Listing 5 – Bug bug2

```c
#include <stdio.h>

int main() {
    int x = 5;
    int y = 3;

    // Bug 1: Incorrect variable in the printf statement
    printf("The value of x is: %d\n", y);

    // Bug 2: Infinite loop
    while (x > 0) {
        printf("x is greater than 0\n");
    }

    return 0;
}
```

bug5.c

Listing 6 – Bug bug5

```c
#include <stdio.h>

int binarySearch(int arr[], int n, int target) {
    int left = 0;
    int right = n - 1;

    while (left <= right) {
        int mid = (left + right) / 2;

        // Bug 1: Incorrect comparison
        if (arr[mid] = target) {  // Should be '==' for comparison, not '='
            return mid;
        } else if (arr[mid] < target) {
            left = mid + 1;  // Bug 2: Update 'left' incorrectly
        } else {
            // Bug 3: Missing update for 'right' in the else case
        }
    }

    return -1;
}

int main() {
  int arr[] = {1, 2, 3, 4, 5, 5, 6, 7, 8, 9, 78};
    int n = sizeof(arr) / sizeof(arr[0]);

    int target = 10;

    int result = binarySearch(arr, n, target);

    if (result != -1) {
        printf("Element %d found at index %d\n", target, result);
    } else {
        printf("Element %d not found in the array\n", target);
    }

    return 0;
}
```

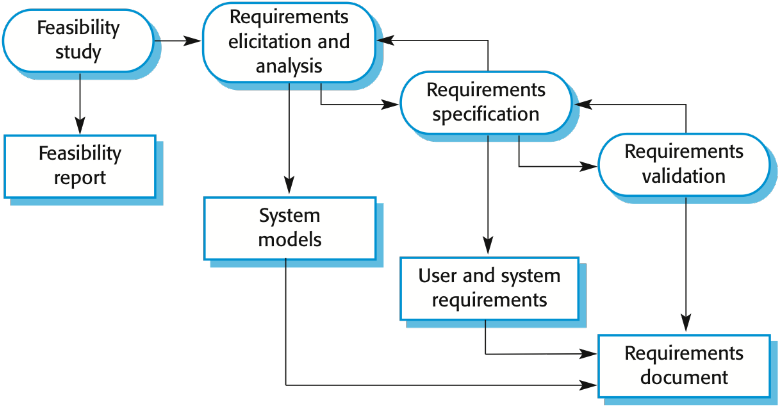
Listing 7 – Bug bug6

```
#include <stdio.h>
#include <limits.h>

int divide(int a, int b) {
    if (b != 0) {
        return a / b;  // Bug: Does not handle overflow
    } else {
        return 0;
    }
}

int main() {
  int x = INT_MIN;
    int y = -1;
    int result = divide(x, y);

    printf("Result: %d\n", result);

    return 0;
}
```

Problem solving

- Defining the problem : *computing the average of two integer numbers*, *computing yje date of Easter for a given year*, *controling the accees of people in a given location*, *managing a vote session*, ...
- Analysing the problem : Is the problem already known ? What are the inputs and the outputs of the problem ? What are the entities involved in the problem ? What is the domain problem (regulations, standards, architectures, ...) ?
- Developing possible solutions : prototypes ? simulations ?
- Evaluating options : scenarios ? questioning the customer ?
- Selecting the best options : questioning the customer ? playing with prototypes ?
- Developing the solution
- Asessing the results.

Software Specification



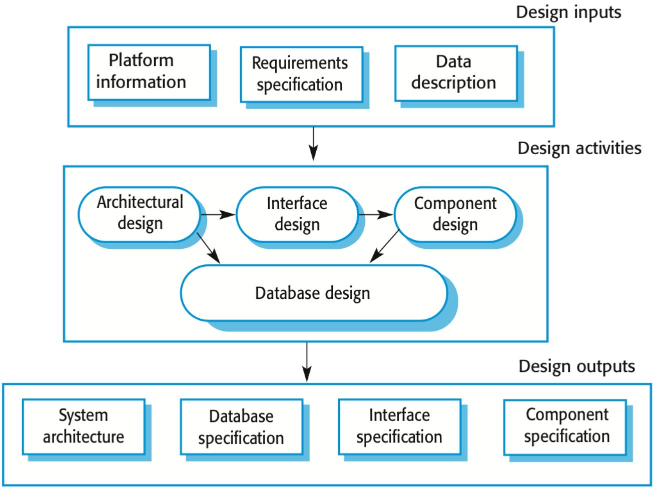
(from Software Engineering by Ian Sommerville)

Requirement Engineering

The process of establishing what services are required and the constraints on the system's operation and development.

- Feasibility study : Is it technically and financially feasible to build the system ?
- Requirements elicitation and analysis : What do the system stakeholders require or expect from the system ?
- Requirements specification : Defining the requirements in detail
- Requirements validation : Checking the validity of the requirements

General Model of the Design Process



(from Software Engineering by Ian Sommerville)

Detecting overflows of computations

Listing 8 – Function average

```
#include <stdio.h>
#include <limits.h>
int average(int a,int b)
{
  return((a+b)/2);
}

int main()
{
  int x,y;
  x=INT_MAX; y=INT_MAX;
  printf("Average for %d and %d is %d\n",x,y,
         average(x,y));
  return 0;
}
```

Execution

Execution produces a result

```
Average  for 2147483647 and 2147483647 is -1
```

Execution

Execution produces a result

```
Average  for 2147483647 and 2147483647 is -1
```

Using frama-c produces a required annotation

```
int average(int a, int b)
{
  int __retres;
  /*@ assert rte: signed_overflow: -2147483648 <= a + b; */
  /*@ assert rte: signed_overflow: a + b <= 2147483647; */
  __retres = (a + b) / 2;
  return __retres;
}
```

Annotated Example 1

Listing 9 – Function average.....

```
#include <stdio.h>
#include <limits.h>
/*@  requires  0 <= a;
     requires a <= INT_MAX ;
     requires  0 <= b;
     requires b <= INT_MAX ;
     requires  0 <= a+b;
     requires a+b <= INT_MAX ;
     ensures \result <= INT_MAX;
*/
int average(int a,int b)
{
  return((a+b)/2);
}

int main()
{
  int x,y;
  x=INT_MAX / 2;y=INT_MAX / 2;
  //  printf("Average  for %d and %d is %d\n",x,y,
  //      );
  return average(x,y);
}
```

Nose Gear Velocity

- Estimated ground velocity of the aircraft should be available only if it is within 3 km/hr of the true velocity at some moment within past 3 seconds

Characterization of a System (I)

- NG velocity system :
  - **Hardware** :
    - *Electro-mechanical sensor* : detects rotations
    - *Two 16-bit counters* : Rotation counter, Milliseconds counter
    - *Interrupt service routine* : updates rotation counter and stores current time.
  - **Software** :
    - *Real-time operating system* : invokes update function every `500 ms`
    - *16-bit global variable* : for recording rotation counter update time
    - *An update function* : estimates ground velocity of the aircraft.
- Input data available to the system :
  - *time* : in `milliseconds`
  - *distance* : in `inches`
  - *rotation angle* : in `degrees`
- Specified system performs velocity estimations in *imperial* unit system
- Note : expressed functional requirement is in *SI* unit system (km/hr).

Characterization of a System (II) cont.

What are the main properties to consider for formalization ?

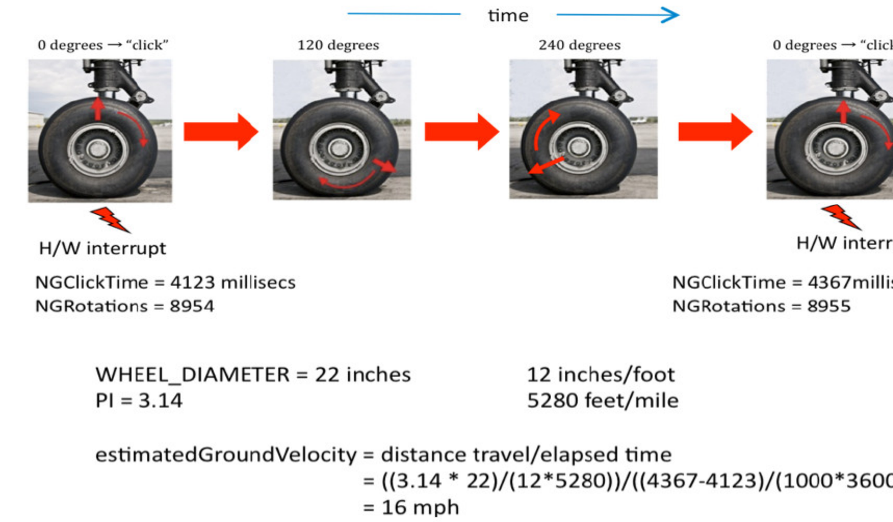
- Two different types of data :
  - counters with modulo semantics
  - non-negative values for time, distance, and velocity
- Two dimensions : *distance* and *time*
- Many units : distance (`inches, kilometers, miles`), time (`milliseconds, hours`), velocity (`kph, mph`)
- And interaction among components

How should we model ?

- Designer needs to consider units and conversions between them to manipulate the model
- One approach : Model units as *sets*, and conversions as constructed types – *projections*.
- Example :

  1 $estimateVelocity \in \mathtt{MILES} \times \mathtt{HOURS} \rightarrow \mathtt{MPH}$
  2 $mphTokph \in \mathtt{MPH} \rightarrowtail\!\!\!\!\rightarrow \mathtt{KPH}$

Sample Velocity Estimation



Safety Property

- Storing the number of `NGClick` in a n-bit variable VNGClick
- Integers are denoted by the set *Int* and is simply defined by the interval *Int*$\hat{=}INT\_MIN..INT\_MAX$.
- Safety requirement :
  The value of `VNGClick` is always in the range of implementation Int or equivalently $VNGClick \in Int$

- $Length = \pi{\cdot}diameter{\cdot}VNGClick$ (mathematical property)
- $Length \leq 6000$ (domain property)
- $\pi{\cdot}diameter{\cdot}VNGClick \leq 6000$
- $VNGClick \leq 6000/(\pi{\cdot}diameter)$
- if n=8, then $2^7-1 = 127$ and $6000/(\pi{\cdot}[22, inch]) = 6000/(\pi{\cdot}55, 88) = 6000/(3, 24{\cdot}[55, 88, cm]) = 6000/(3, 24{\cdot}0.5588) \approx 3419$ and the condition of safety can not be satisfied in any situation.
- if n=16, then $2^{15}-1 = 65535$ and $6000/(\pi{\cdot}[22, inch]) \approx 3419$ and the condition of safety can be satisfied in any situation since $3419 \leq= 65535$.

Safety Property

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- Integers are denoted by the set *Int* and is simply defined by the interval *Int*$\hat{=} INT\_MIN..INT\_MAX$.
- Safety requirement :
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$$RTE\_VNGClick : 0 \leq vNGClick \leq INT\_MAX \tag{1}$$

- The current value of VNGClick is always bounded by the two values 0 and INT_MAX.

Computing the date of easter

Easter is the Sunday following the first full moon of spring, that is, according to the definition established by the Council of Nicea in 325 : "Easter is the Sunday following the 14th day of the Moon which reaches that age on or immediately after March 21."
According to this definition, Easter falls between March 22 and April 25 of each year.

- Easter date 2019 : 20 march / 21 avril
- Easter date 2020 : 7 april / 12 april
- Easter date 2021 : 28 march / 4 april
- Easter date 2022 : 16 april / 17 april 2022
- Easter date 2023 : 6 april / 9 april 2023
- Easter date 2024 : 25 march / 31 march 2024
- Easter date 2025 : 12 april / 20 april 2025
- Easter date 2026 : 2 april / 5 april 2026

Computing the date of easter

- The year is given as a number `year`
- The date of Easter is computed as a date `day` and `month`

General Protocol for Computing the Date of Easter

- Easter is a Sunday.
- Date of the spring full moon `full-moon-day` and `full-moon-month` from the 21st of March.
- `full-moon-month` is either 3 or 4.
- The earliest date if March 22nd
- Determine the First Sunday just after the spring full moon

Using the C function

Listing 10 – Using C function for date of Easter

```
********************
* year * day * month *
********************
* 2019 * 21 * April *
********************
* 2020 * 12 * April *
********************
* 2021 *  4 * April *
********************
* 2022 * 17 * April *
********************
* 2023 *  9 * April *
********************
* 2024 * 31 * March *
********************
* 2025 * 20 * April *
********************
* 2026 *  5 * April *
********************
********************
```

Analyzing the protocol and its requirements

- The day of Spring namely March 21 : $dspring = (21, 3)$ (**domain property**)
- The table of Full Moon of the current year : $tfullmoon[NFM]$ (**domain property**))
- Computing the date of the first full moon of Spring : $dfullmoon = tfullmoon[i]$ where $i \in 0..NFM-1$ (**algorithmic property**)
- Computing the date of the next Sunday starting from $nextday(dfullmoon)$ (**algorithmic property**)

Tryptich $\mathcal{D}, \mathcal{A}$ sat $\mathcal{R}$

- $\mathcal{D}$ (domain of problem) contains informations on Moon Phases.
- $\mathcal{R}$ (requirements or prescription) expresses the day of Easter following the rule.
- $\mathcal{A}$ (algorithm or program or protocol) contains the different algorithms used for computing necessary informations.

Verification and Validation

- Verification : techniques and tools applied to check the *internal* relationship between the three components $\mathcal{D}, \mathcal{A}, \mathcal{R}$
- Validation : techniques and tools applied to check the *external* relationship between the three components $\mathcal{D}, \mathcal{A}, \mathcal{R}$ and external entities.

Computing the number of days for waiting a given future date ?

You may want to gt the number of days between the current day and a future day :

- Number of days until Christmas
- Number of days until Retirement
- Notification of an event three days before a given date.
- ...

What is the next day of agiven date ?

- Domain Properties related to dates and calendars :
  - A year is made up of 12 months
  - There are two kinds of months 30 days and 31 days but one month has 28 days and 29 days when the year is a leapyear.
- Mathematical definition of a leapyear

Listing 11 – pre/post specification for leapyear(int year)

```
#ifndef _LEAP_H

/*@ requires -5000 <= year;
  @ ensures year % 400 == 0  ==> \result == 1;
  @ ensures year % 400 != 0 && year % 100 != 0  && year % 4 == 0 ==> \result == 1;
  @ ensures year % 400 != 0  &&  year % 100 != 0  && year % 4 != 0 ==> \result == 0;
  @ ensures \result == 1 ==>(year % 400 == 0 ) || ( year % 400 != 0 && year % 100 != 0  && year % 4
  @ ensures \result == 0 ==>(year % 400 != 0) && ( year % 400 == 0 || year % 100 == 0  || year % 4
 */
int leapyear(int year);

#endif
```

Defining leapyear(int year)

Listing 12 – Using C function for date of Easter

```
#include "leapyear.h"

  int leapyear(int year)
{
  int r=0;// = 0;
 // leap year if perfectly divisible by 400
   if (year % 400 == 0) {
     r = 1; //printf("%d is a leap year.", year);
   }
   // not a leap year if divisible by 100
   // but not divisible by 400
   else if (year % 100 == 0) {
     r=0;// printf("%d is not a leap year.", year);
   }
   // leap year if not divisible by 100
   // but divisible by 4
   else if (year % 4 == 0) {
     r=1; // printf("%d is a leap year.", year);
   }
   // all other years are not leap years
   else {
     r=0; // printf("%d is not a leap year.", year);
   };

   return r;
}
```

Computing a sequence of dates

- Computing the number of days from `fromdate` till `todate` is following a sequence :
  $d_0 = fromdate \stackrel{nextday}{\longrightarrow} d_1 \stackrel{nextday}{\longrightarrow} d_2 \ldots \stackrel{nextday}{\longrightarrow} d_{n-1} \stackrel{nextday}{\longrightarrow} d_n = todate$
- The value pf n is not known and is in fact the number we want to compute.
- Define a function `nextday` which is returning the next day of a given day.
- A date is a triple as (d,m,y) and is satisfying the function :

Listing 13 – checkdate(struct date now)

```
#include "structure.h"
#include "leapyear.h"
struct date;
#include "checkdate.h"

int checkdate(struct date now)
{
int r=0;
int day=now.day, month=now.month, year=now.year, aleapday;
int  aleapyear=leapyear(year);
    if ( month == 12 || month == 1 || month == 3 || month == 5 || month == 7 || month == 8 || month
      if (1 <= day && day <= 31) {r=1;};
    } else if (month == 4 || month == 6 || month == 9 || month == 11) {
      if (1 <= day && day <= 30) {r=1;};
    } else if  ( aleapyear==1 && month == 2 ) {
      if (1 <= day && day <= 29) {r=1;};
     } else if  ( aleapyear==0 && month == 2) {
      if (1 <= day && day <= 28) {r=1;}; };
    return r;
```

nextday(struct date now)

Listing 14 – nextday(struct date now)

```
#include "structure.h"
#include "leapyear.h"
#include "checkdate.h"
 struct date;
#include "nextday.h"

 struct date  nextday(struct date now)
 {

   struct date r;
 int day=now.day, month=now.month, year=now.year, aleapday;
 int  aleapyear=leapyear(year);
 int nday=day, nmonth=month, nyear=year;
     if ( month == 12 || month == 1 || month == 3 || month == 5 || month == 7 || month == 8 || month == 10
       if (day <31) {nday=day+1;} else if (day == 31 && month != 12) {nday=1;nmonth=month+1;} else {nday=1
     } else if (month == 4 || month == 6 || month == 9 || month == 11) {
      if (day <30) {nday=day+1;} else if (day == 30 ) {nday=1;nmonth=month+1;};
     } else if  ( aleapyear==1 && month == 2 && day == 29 ) {nday=1; nmonth=3;}
     else if  ( aleapyear==1 && month == 2 && day != 29 ) {nday=day+1;}
     else if  ( aleapyear==0 && month == 2 && day == 28 ) {nday=1; nmonth=3;}
     else if  ( aleapyear==0 && month == 2 && day != 28 ) {nday=day+1;}
     else  {nday=day + 1;}

     r.day = nday;
     r.month = nmonth;
     r.year = nyear;
     return r;
 }
```

Listing 15 – int daytilldate(struct date currentdate,struct date futuredate)

```
#include "structure.h"
#include "leapyear.h"
#include "checkdate.h"
#include "nextday.h"
struct date;
#include "daytilldate.h"

int daytilldate(struct date currentdate,struct date futuredate)
{
  int r=0;
  struct date d=currentdate;
  while (d.day != futuredate.day || d.month != futuredate.month || d.year != futuredate.year) {
    r++;
    d = nextday(d);
  };

  return r;
}
```

Context and Objectives

- Software Systems assist our dayly lifes
- Questions on dependability and security assurance shoud be addressed
- Questions on certification with respect to norms and standards
- Improving the life-cycle development for addressing these questions

Critical System

Critical systems are systems in which defects could have a dramatic impact on human life or the environment.

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System failure

Software failure or fault of complex systems is the major cause in the software crisis. For example,

- Therac-25 (1985-1987) : six people overexposed through radiation.
- Cardiac Pacemaker (1990-2002) : 8834 pacemakers were explanted.
- Insulin Infusion Pump (IIP) (2010) : 5000 adverse events.

Critical Systems

- Safety-critical systems : A system whose failure may result in injury, loss of life or serious environmental damage. **An example of a safety-critical system is a control system for a chemical manufacturing plant.**
- Mission-critical systems : A system whose failure may result in the failure of some goal-directed activity. **An example of a mission-critical system is a navigational system for a spacecraft.**
- Business-critical systems : A system whose failure may result in very high costs for the business using that system. **An example of a business-critical system is the customer accounting system in a bank.**

Issue

The high costs of failure of critical systems means that trusted methods and techniques must be used for development.

Legacy systems

- Legacy systems are socio-technical computer-based systems that have been developed in the past, often using older or obsolete technology.
- Legacy systems include not only hardware and software but also legacy processes and procedures ;old ways of doing things that are difficult to change because they rely on legacy software. Changes to one part of the system inevitably involve changes to other components.
- Legacy systems are often business-critical systems. They are maintained because it is too risky to replace them.
- For example, for most banks the customer accounting system was one of their earliest systems.

Software Process

A software process is a structured set of activities required to develop a software system : Spiral Model, Waterfall Model, V-Shaped Model, etc.

A software process involve the following steps :

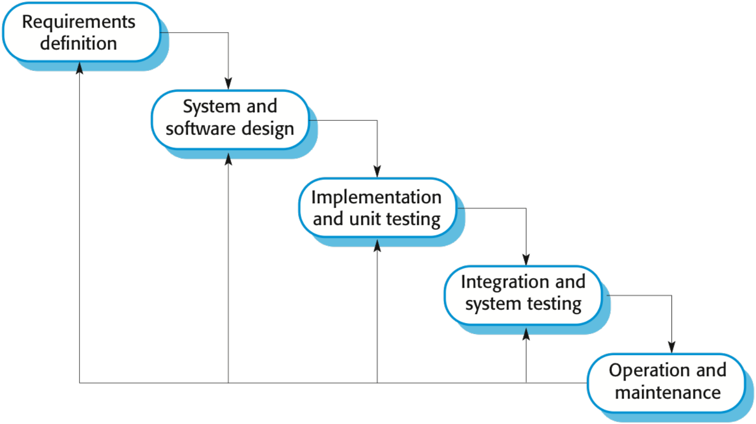
- Specification *defining what the system should do ;*
- Design and implementation *defining the organization of the system and implementing the system ;*
- Validation *checking that it does what the customer wants ;*
- Evolution *changing the system in response to changing customer needs.*

software process model

A software process model is an abstract representation of a process. It presents a description of a process from some particular perspective.

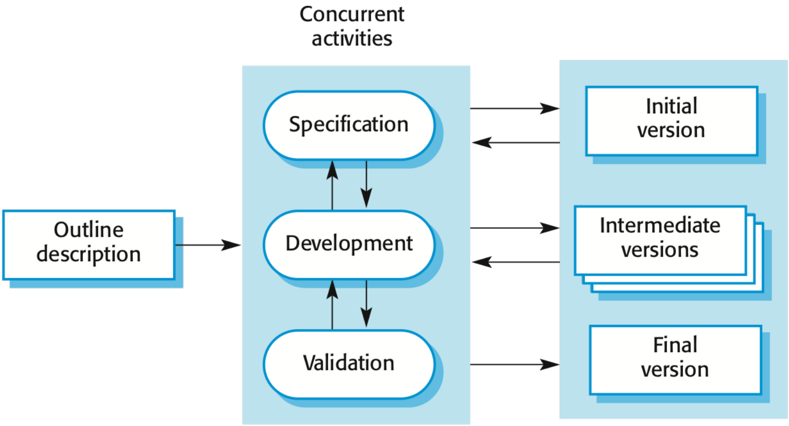
- The waterfall model : Plan-driven model ; Separate and distinct phases of specification and development.
- Incremental development : Specification, development and validation are interleaved ; plan-driven or agile.
- Reuse-oriented software engineering : The system is assembled from existing components ; plan-driven or agile.

The Waterfall Model



(from Software Engineering by Ian Sommerville)

The Incremental Model



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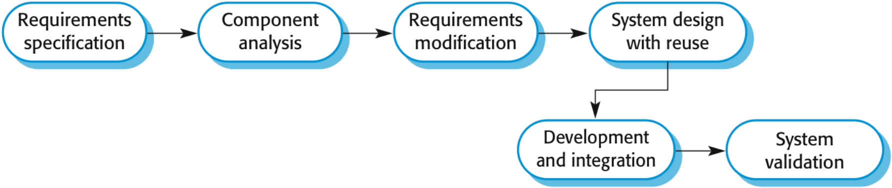
Reuse-oriented software engineering



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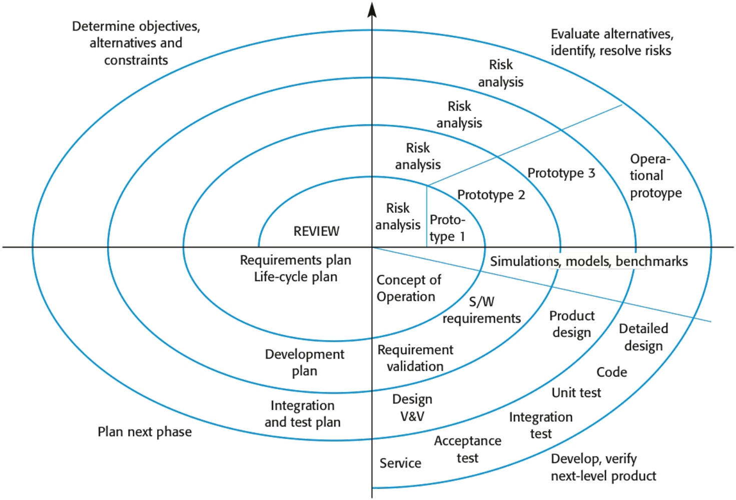
Boehm's spiral model of the software process



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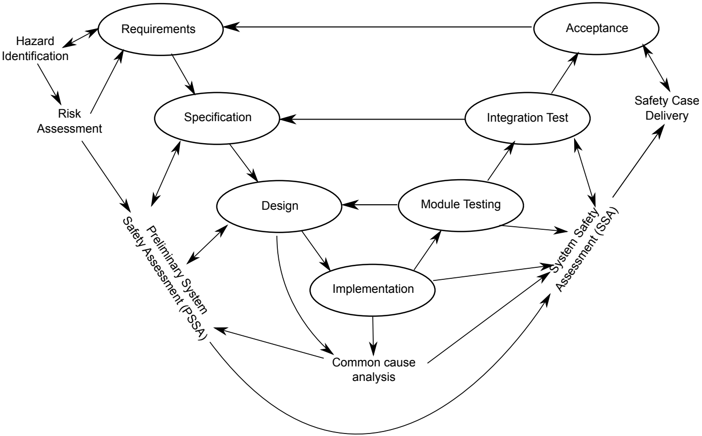
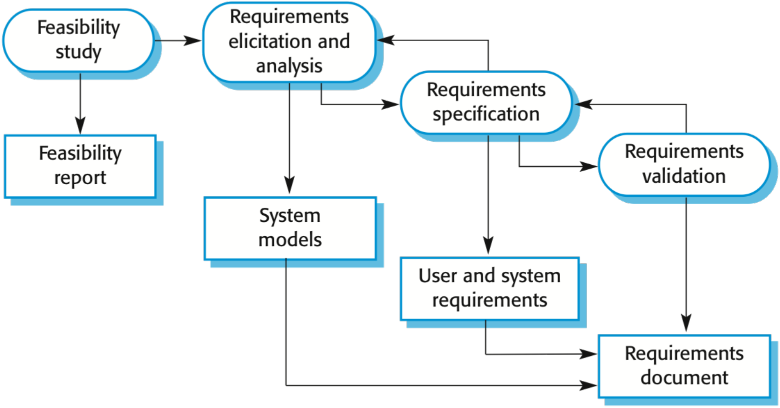
V & V Model



(from Software Engineering by Ian Sommerville)

Software Specification



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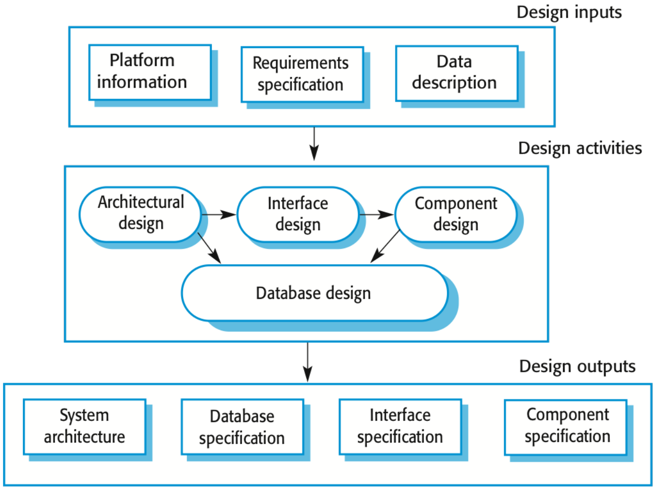
Requirement Engineering

The process of establishing what services are required and the constraints on the system's operation and development.

- Feasibility study : Is it technically and financially feasible to build the system ?
- Requirements elicitation and analysis : What do the system stakeholders require or expect from the system ?
- Requirements specification : Defining the requirements in detail
- Requirements validation : Checking the validity of the requirements

General Model of the Design Process



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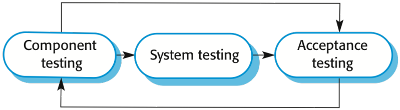
- Verification and validation (V & V) : intended to show that a system conforms to its specification and meets the requirements of the system customer ; involves checking and review processes and system testing.
- System testing : involves executing the system with test cases that are derived from the specification of the real data to be processed by the system.
- Testing is the most commonly used V & V activity



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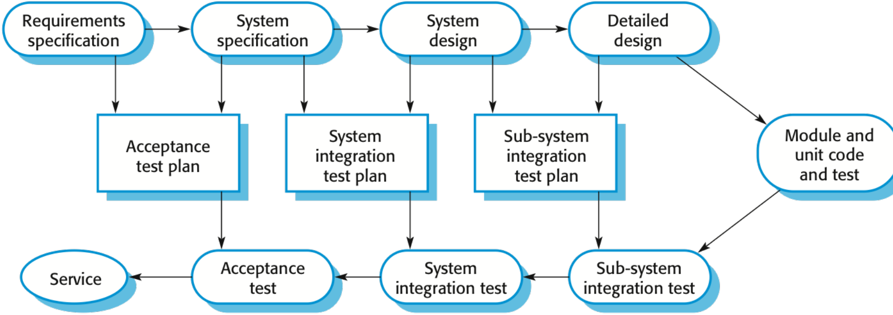
- Verification of software with respect to contract : **posthoc verification, semantic analysis, refinement-based methodology. . .**

Testing phases in a plan-driven software process



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SIL

Safety integrity level (SIL) is defined as a relative level of risk-reduction provided by a safety function, or to specify a target level of risk reduction. In simple terms, SIL is a measurement of performance required for a safety instrumented function (SIF).

- The European functional safety standards based on the IEC 61508 standard defines four SILs (with SIL 4 the most dependable and SIL 1 the least).
- A SIL is determined based on a number of quantitative factors in combination with qualitative factors such as development process and safety life cycle management.

The IEC 61508 standard

- Probability of Failure on Demand during 10 years.
- SILs :
  - SIL4 : Conséquence très importante sur la communauté entraînant une réduction du danger de 10 000 à 100 000.
  - SIL3 : Conséquence très importante sur la communauté et les employés entraînant une réduction du danger de 1 000 à 10 000.
  - SIL2 : Protection importante de l'installation, de la production et des employés entraînant une réduction du danger de 100 à 1000.
  - SIL1 : Faible protection de l'installation, de la production entraînant une réduction du danger de 10 à 100.

Grâce à une grande maîtrise en calcul formel, en sécurité de fonctionnement et à l'utilisation de la méthode B (beaucoup utilisée en milieu industriel pour réaliser des logiciels sécuritaires prouvés), ClearSy System Engineering est qualifiée pour mener à bien des projets nécessitant un contexte de certification de niveau SIL 2, SIL 3, ou SIL 4, selon la norme 61508.

Verification and Validation

- Validation : *Are we building the right product*
- Verification : *Are we building the process right ?*

verification

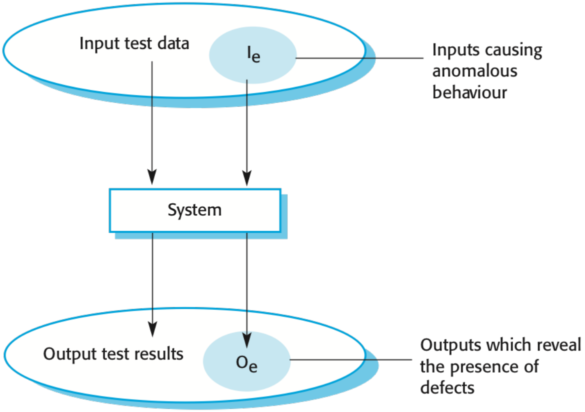
The verification aims to check that the software meets its stated functional and non-functional requirements.

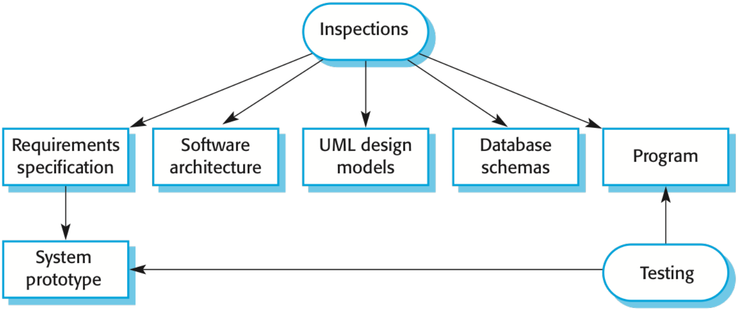
- *functional requirements*
- *non-functional requirements*

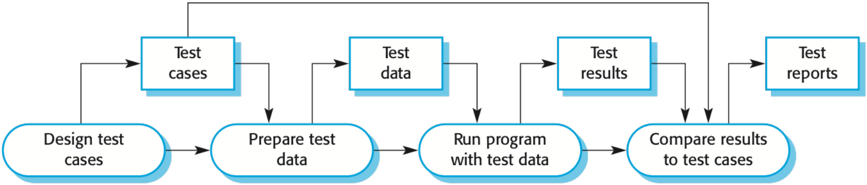
validation

The verification aims to ensure that the software meets the customer's expectations.

An input-output model of program testing




Inspections
Requirements specification
Software architecture
UML design models
Database schemas
Program
System prototype
Testing


Test
cases
Test
data
Test
results
Test
reports
Design test
cases
Prepare test
data
Run program
with test data
Compare results
to test cases

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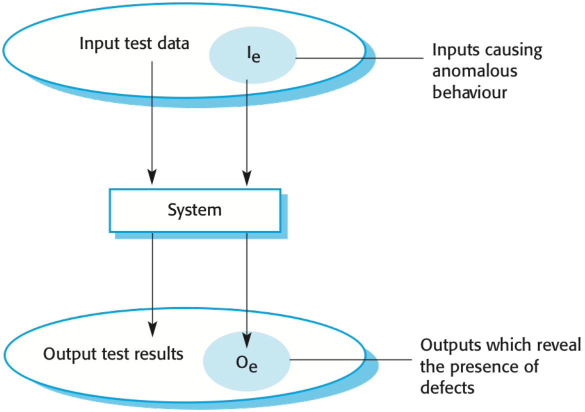

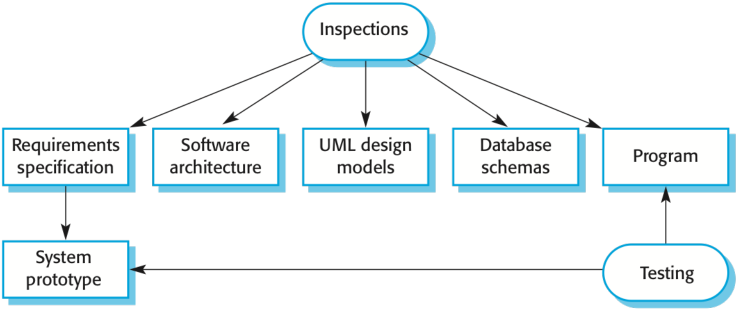
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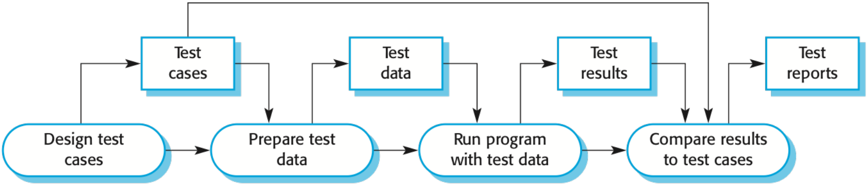


Test cases
Test data
Test results
Test reports
Design test cases
Prepare test data
Run program with test data
Compare results to test cases

The Cleanroom Model

- The Cleanroom method, developed by the late Harlan Mills and his colleagues at IBM and elsewhere, attempts to do for software what cleanroom fabrication does for semiconductors : to achieve quality by keeping defects out during fabrication.
- In semiconductors, dirt or dust that is allowed to contaminate a chip as it is being made cannot possibly be removed later.
- But we try to do the equivalent when we write programs that are full of bugs, and then attempt to remove them all using debugging.

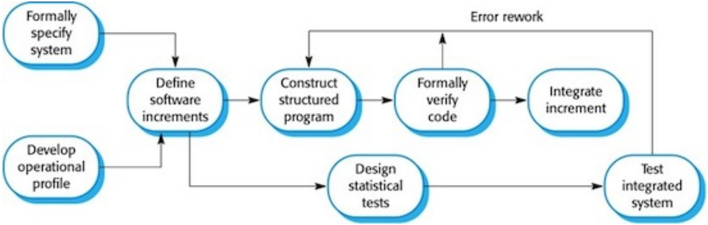
The Cleanroom method, then, uses a number of techniques to develop software carefully, in a well-controlled way, so as to avoid or eliminate as many defects as possible before the software is ever executed. Elements of the method are :

- specification of all components of the software at all levels ;
- stepwise refinement using constructs called "box structures" ;
- verification of all components by the development team ;
- statistical quality control by independent certification testing ;
- no unit testing, no execution at all prior to certification testing.

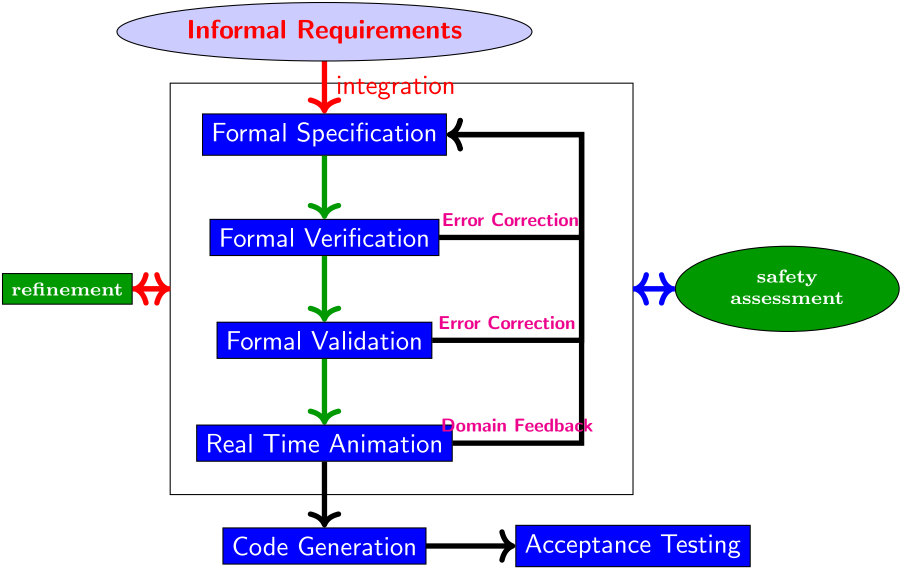
Software development in five key strategies

- Formal specification : The software to be developed is formally specified. A state-transition model which shows system responses to stimuli is used to express the specification.
- Incremental development : The software is partitioned into increments which are developed and validated separately using the Cleanroom process. These increments are specified, with customer input, at an early stage in the process.
- Structured programming : Only a limited number of control and data abstraction constructs are used. The program development process is a process of stepwise refinement of the specification. A limited number of constructs are used and the aim is to apply correctness-preserving transformations to the specification to create the program code.
- Static verification : The developed software is statically verified using rigorous software inspections. There is no unit or module testing process for code components.
- Statistical testing of the system : The integrated software increment is tested statistically, to determine its reliability. These statistical tests are based on an operational profile which is developed in parallel with the system specification.

Diagram for the Cleanroom Model



Critical System Development Life-Cycle Methodology



Overview of Methodology

- Informal Requirements : Restricted form of natural language.
- Formal Specification : Modeling language like Event-B , Z, ASM, VDM, TLA+. . .
- Formal Verification : Theorem Prover Tools like PVS, Z3, SAT, SMT Solver. . .
- Formal Validation : Model Checker Tools like ProB, UPPAAL , SPIN, SMV . . .
- Real-time Animation : **Our proposed approach . . . Real-Time Animator . . .**
- Code Generation : **Our proposed approach . . . EB2ALL : EB2C, EB2C++, EB2J, EB2C# . . .**
- Acceptance Testing : Failure Mode, Effects and Critically analysis(FMEA and FMEA), System Hazard Analyses(SHA)

- Typing Properties using Typechecker (see for instance functional programming languages as ML, CAML, OCAML, ...)
- Invariance and safety (A *nothing bad will happen !*) properties for a program P :
  - Transformation of P into a relational model M simulating P
  - Expression of safety properties : $\forall s, s' \in \Sigma.(s \in Init_{\mathrm{S}} \wedge s \xrightarrow{\star} s') \Rightarrow (s' \in A)$.
  - Definition of the set of reachable states of P using M : $\textsc{reachable}(\mathrm{M}) = Init_{\mathrm{S}} \cup \longrightarrow [\textsc{reachable}(\mathrm{M})]$
  - Main property of $\textsc{reachable}(\mathrm{M})$: $\textsc{reachable}(\mathrm{M}) \subseteq A$
  - Characterization of $\textsc{reachable}(\mathrm{M})$: $\textsc{reachable}(\mathrm{M}) = \mathrm{FP}(\textsc{reachable}(\mathrm{M}))$

Problems

- Proving automatically $\textsc{reachable}(\mathrm{M}) \subseteq A$:

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- Proving automatically $\textsc{reachable}(\mathrm{M}) \subseteq A$: approximating semantics of programs

Decidability or Undecidability

Decidability or Undecidability

- A problem $x \in P$ is generally stated by the function $\chi_{x \in P}$ where $\chi_{x \in P}(u) = 1$, if $P(u)$ is true and $\chi_{x \in P}(u) = 0$, if $P(u)$ is false :
  - Problem 1 : $x \in 0..n$ where $n \in \mathbb{N}$
  - Problem 1 : $w \in \mathcal{L}(G)$ where G is a grammar over the finite set of alphabet symbols Σ and $\mathcal{L}(G) \subseteq \Sigma^\star$.

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- Problem of the correctness of a program :
  - Assume that $\mathcal{F}$ is the set of unary function over natural numbers : $\mathcal{F} = \mathbb{N} \nrightarrow \mathbb{N}$.
  - $\mathcal{C} \subseteq \mathcal{F}$: the set of computable (or programmable) functions is $\mathcal{C}$
  - $f \in \mathcal{C} = \{\Phi_0, \Phi_1, \ldots, \Phi_n, \ldots\}$: the set of computable functions is denumerable.
  - The problem $x \in dom(\Phi_y)$ is not decidable and it expresses the correctness of programs.

Quelques observations

Implicite versus explicite

- Ecrire $\mathit{101} = \mathit{5}$ peut avoir une signification

Implicite versus explicite

- Ecrire *101* $=$ *5* peut avoir une signification
- Le code du nombre n est *101* à gauche du symbole $=$ et le code du nombre n est sa représentation en base 10 à droite.
- $n_{10} = 5$ et $n_2 = 101$
- Vérification : $base(2, 10, 101) = 1.2^2+0.2+1.2^0 = 5_{10}$

Example : description of static behaviour

- A train moving at absolute speed $spd1$
- A person walking in this train with relative speed $spd2$
  - One may compute the absolute speed of the person
- Modelling
  - Syntax. Classical expressions
    - Type $Speed = Float$
    - $spd1, spd2 : Speed$
    - $AbsoluteSpeed = spd1{+}spd2$
  - Semantics
    - If $spd1 = 25.6$ and $spd2 = 24.4$ then $AbsoluteSpeed = 50.0$
    - If $spd1 = "val"$ and $spd2 = 24.4$ then exception raised
  - Pragmatics
    - What if $spd1 is$ given in mph (miles per hour) and $spd2$ in km/s (kilometers per second) ?
    - What if $spd1$ is a relative speed ?

Intuition

- Un programme P *produit* des résultats à partir de données en accord avec une sémantique :
  - STATES est l'ensemble de tous les états de P : $STATES = \mathrm{X} \rightarrow \mathbb{Z}$ où X désigne les variables de P.
  - s_0 et s_f deux états de STATES : $\mathcal{D}(P)(s_0) = s_f$ signifie que P est exécuté à partir d'un état s_0 et produit un état s_f.
  - Pour un état s de P courant, on notera $s(X) = x$ pour distinguer la valeur de la variable X et sa valeur courante en s :

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- Un programme P *remplit* un contrat (pre,post) :
  - P transforme une variable x à partir d'une valeur initiale x_0 et produisant une valeur finale x_f : $x_0 \xrightarrow{\mathsf{P}} x_f$
  - x_0 satisfait pre : $\mathsf{pre}(x_0)$
  - x_f satisfait post : $\mathsf{post}(x_0, x_f)$
  - $\mathsf{pre}(x_0) \wedge x_0 \xrightarrow{\mathsf{P}} x_f \Rightarrow \mathsf{post}(x_0, x_f)$

Vérification du contrat

Un programme P *remplit* un contrat (pre,post) :

- P transforme une variable x à partir d'une valeur initiale x_0 et produisant une valeur finale x_f : $x_0 \xrightarrow{\mathsf{P}} x_f$
- x_0 satisfait pre : pre(x_0) and x_f satisfait post : post(x_0, x_f)
- pre$(x_0) \wedge x_0 \xrightarrow{\mathsf{P}} x_f \Rightarrow$ post(x_0, x_f)

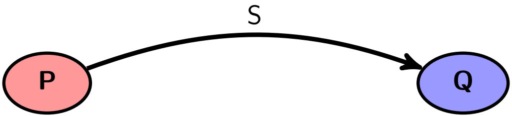
requires $pre(x_0)$
ensures $post(x_0, x_f)$
variables X

begin
$0 : P_0(x_0, x)$
$\texttt{instruction}_0$
$\ldots$
$i : P_i(x_0, x)$
$\ldots$
$\texttt{instruction}_{f-1}$
$f : P_f(x_0, x)$
end

- $pre(x_0) \wedge x = x_0 \Rightarrow P_0(x_0, x)$
- $P_f(x_0, x) \Rightarrow post(x_0, x)$
- some conditions for verification related to pairs $\ell \longrightarrow \ell'$

Asserted Program $\{P\}\ S\ \{Q\}$

$$\{P\}\ S\ \{Q\}$$



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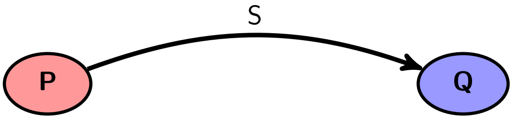

- {P} S {Q} : *asserted program*

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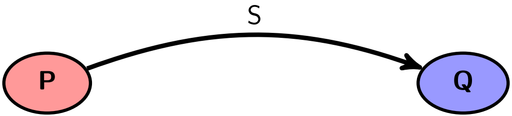
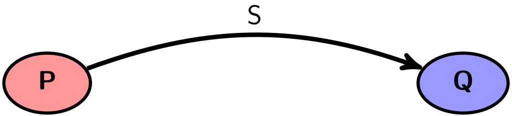


- {P} S {Q} : *asserted program*
- P $\Rightarrow WP(S)$(Q) : *logical formula*

{P} S {Q}



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- C(S) $\vdash$ P $\Rightarrow WP(S)$(Q) : *logical formula*

Asserted Program $\{P\}$ S $\{Q\}$

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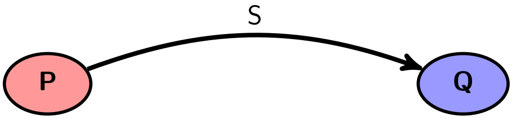
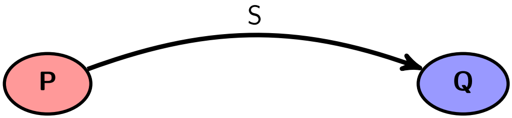


- $\{P\}$ S $\{Q\}$: *asserted program*
- P $\Rightarrow WP(S)(Q)$: *logical formula*
- C$(S) \vdash$ P $\Rightarrow WP(S)(Q)$: *logical formula*
- $SP(S)(P) \Rightarrow$ Q : *logical formula*

Asserted Program {P} S {Q}

{P} S {Q}



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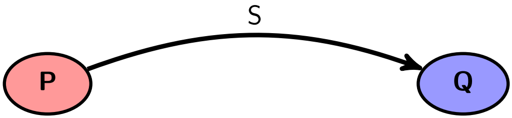

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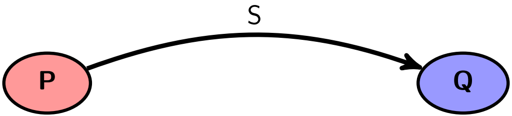
{P} S {Q}



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- C(S) $\vdash SP(S)$(P) $\Rightarrow$ Q : *logical formula*

Predicate Transformer

$WP(S)$(Q) is the Weakest-Precondition of S for Q and is a predicate transformer but $WP(S)(.)$ is not a computable function over the set of predicates.

Summary

Summary

Modelling, specification and verification

Modelling, specification and verification

- Set-theoretical notations using the Eevent-B modelling language
- Relational modelling of a program or an algorithm
- Program properties as safety, invariance, pre and post conditions
- Design by contract
- Method for proving invariance properties of programs and induction principles as Floyd's method, Hoar logics,
- Techniques for Model-Checking
- Tools : the toolset RODIN, the toolset TLAPS, the toolset PAT, the toolset Eiffel Studio, the toolset Frama-c, . . .

Summary

Summary

Logics

Logics

- Propositional Formulae and first order formulae
- Models
- Sequents Calculus
- Proofs and deduction
- Resolution
- Tools : the toolset Rodin

Summary

Fixed-Point Theory

Fixed-Point Theory

- Complete Partiallly Ordered Sets (CPO) and Complete Lattices
- Fixed-Point Theorems : Kleene, Tarski, . . .
- Abstract Interpretation
- Galois Lattices
- Static analysis of Programs by abstract interpretation.
- Semantics of programs

Summary

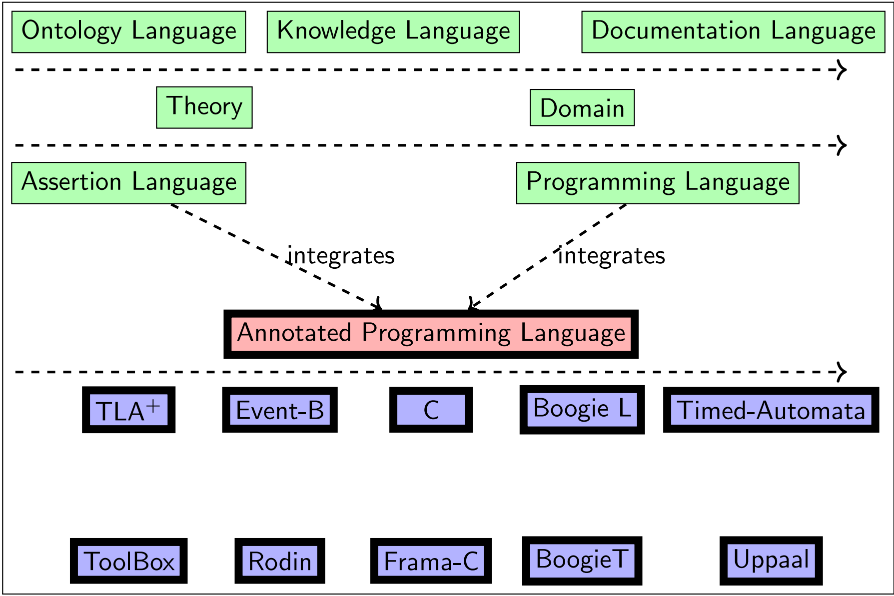
Summary

Computability, Decidability, complexity, Undecidabiliy

Computability, Decidability, complexity, Undecidabiliy

- Models of computing : Turing Machines, Partially Recursive Functions, URM, ...
- Church's Thesis
- Decidability
- Undecidability
- Complexity

Summry of concepts



Summary

Summary

Tools

Summary

Tools

- The TLA$^+$ ToolBox
- The RODIN platform
- Frama-C
- Boogie and the Visual Studio Suite
- UPPAAL

Informations et méthodologie du cours

- Documents sur Arche MODÈLES ET ALGORITHMES avec le mot de passe *mery2023*
- Alternance des cours et des TDs avec des séances sur machines.
- Intervention de Rosemary Monahan de NUI Maynooth en cours d'année pour un cours et un TD dupliqué pour IL.
- Deux groupes de TD
- Machine virtuelle et machines telecom avec les logiciels installés.