QRS 2015, Vancouver

Integrating Specification Animation with Specification-Based Program Testing and Inspection for Software Quality Assurance

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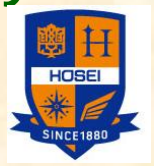

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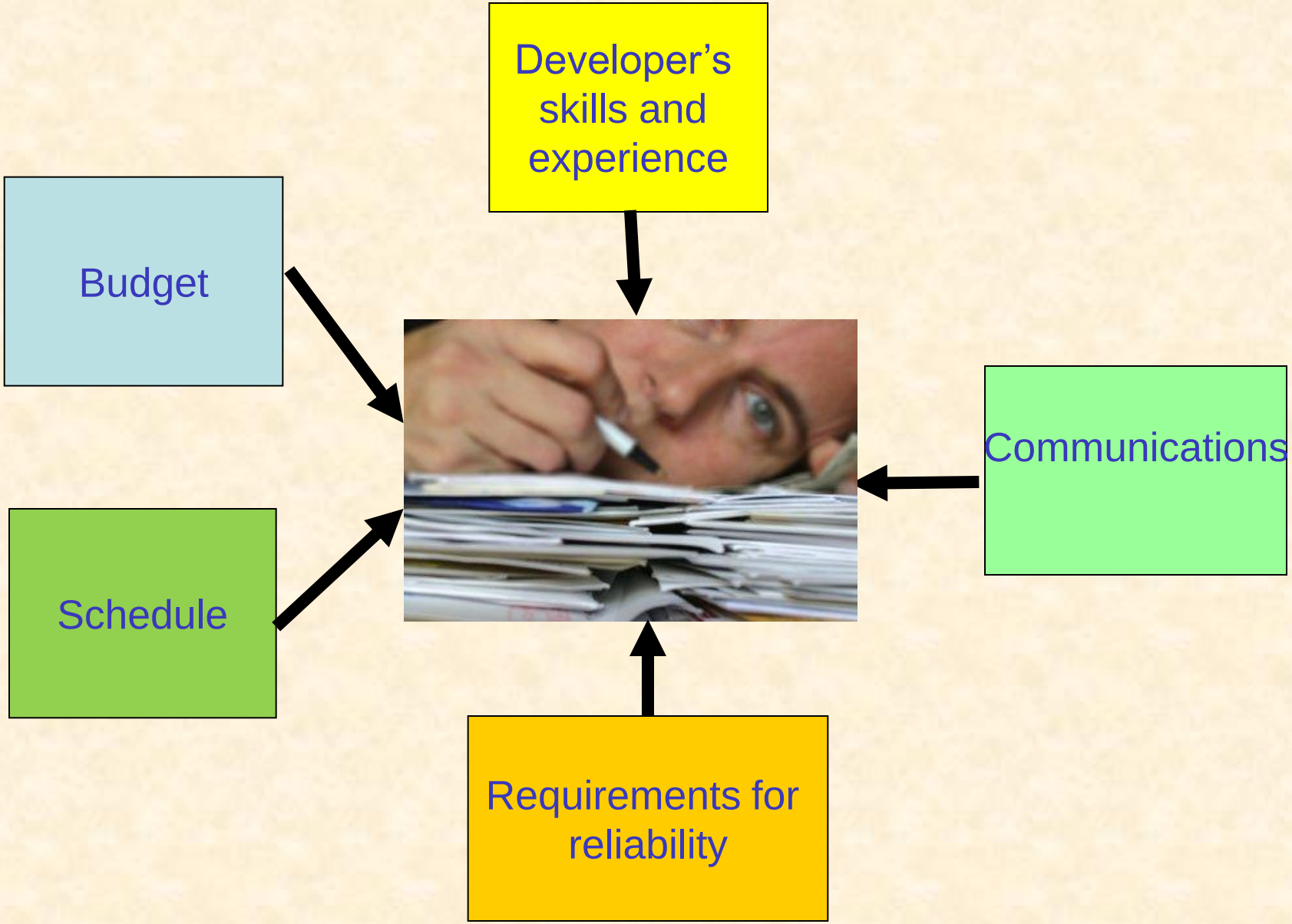
Overview

1. Challenges to Software Quality Assurance
2. Our Solution
3. Specification Animation
4. Specification-Based Program Testing and Inspection
5. Open Problems
6. Conclusions
7. Future Work

1. Challenges to Software Quality Assurance

- The scale and complexity of software development projects
  - The scale of documentation
  - The complexity of documentation
  - The complexity of situations (e.g., requirements changing, people moving, client complaining, manager worrying, and developer fighting)

The constrained development environment



➢ Deficiencies of techniques available for use

- Formal proof of correctness: ideal but tedious, ineffective (for faulty programs), requiring skills (loop invariants), error-prone, and time consuming.
- Model checking: needs appropriate abstraction of a real system to a FSM model and faces the state explosion problem (two state space explosions for software: initial state space and program state space).
- Testing: can tell the existence of bugs, but cannot tell their absence in general. Nevertheless, it is a common practice in industry.
- Review and inspection: easy to carry out, but heavily depend on human judgment, ability, and experience.

Harsh reality

Manager:

Why is the project over budget and behind schedule?

Client:

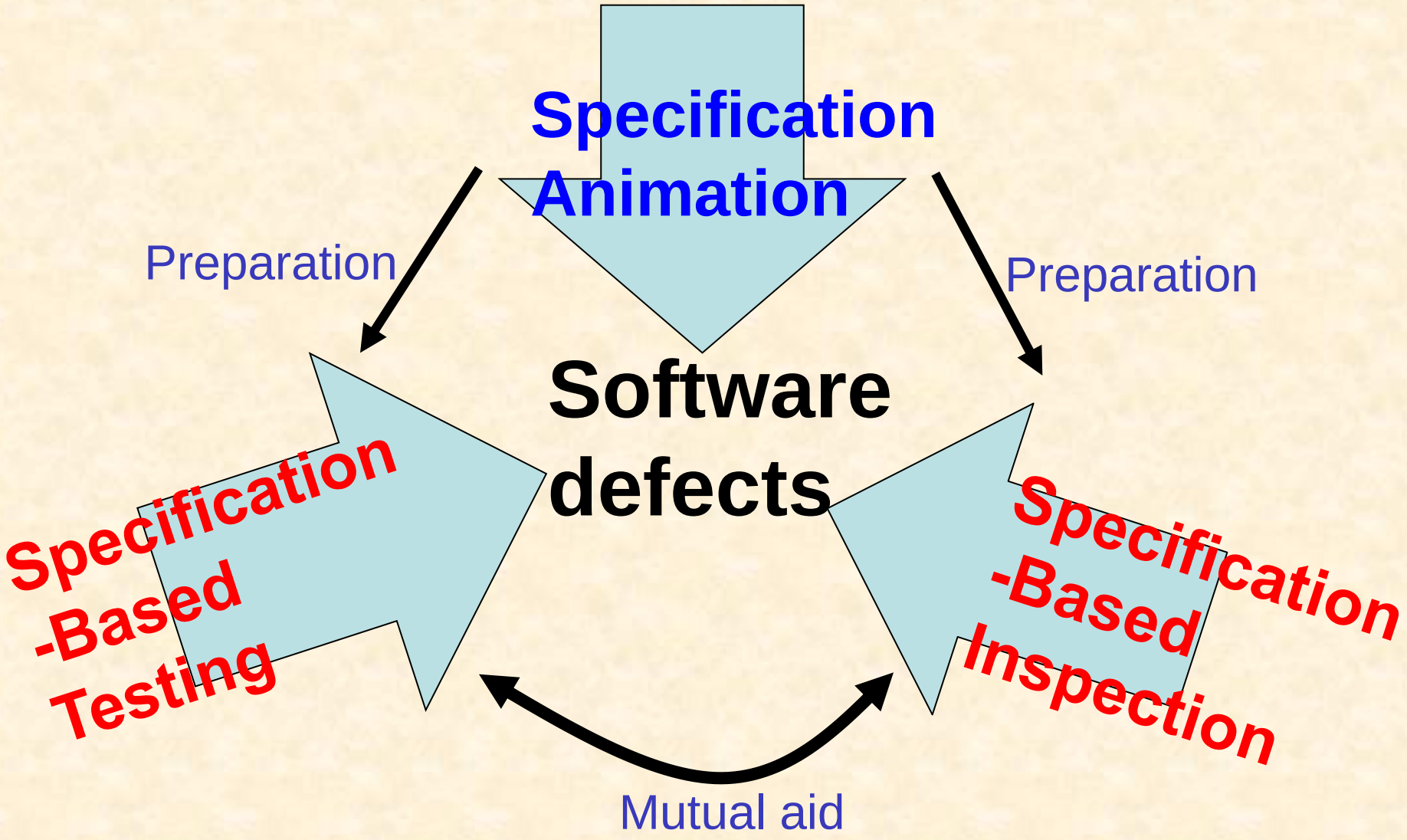
Why does the software system behaves differently from my requirements?

Developer:

Why are there so many bugs remaining in the program?

Why is my own program difficult to understand even by myself?

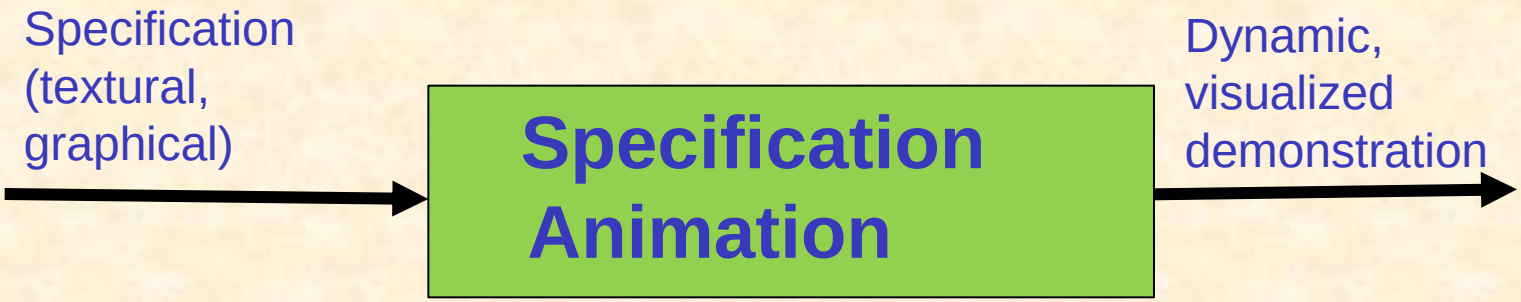
2. Our Solution



3. Specification Animation

Specification animation is a technique for dynamic and visualized demonstration of the system behaviors defined in the specification.

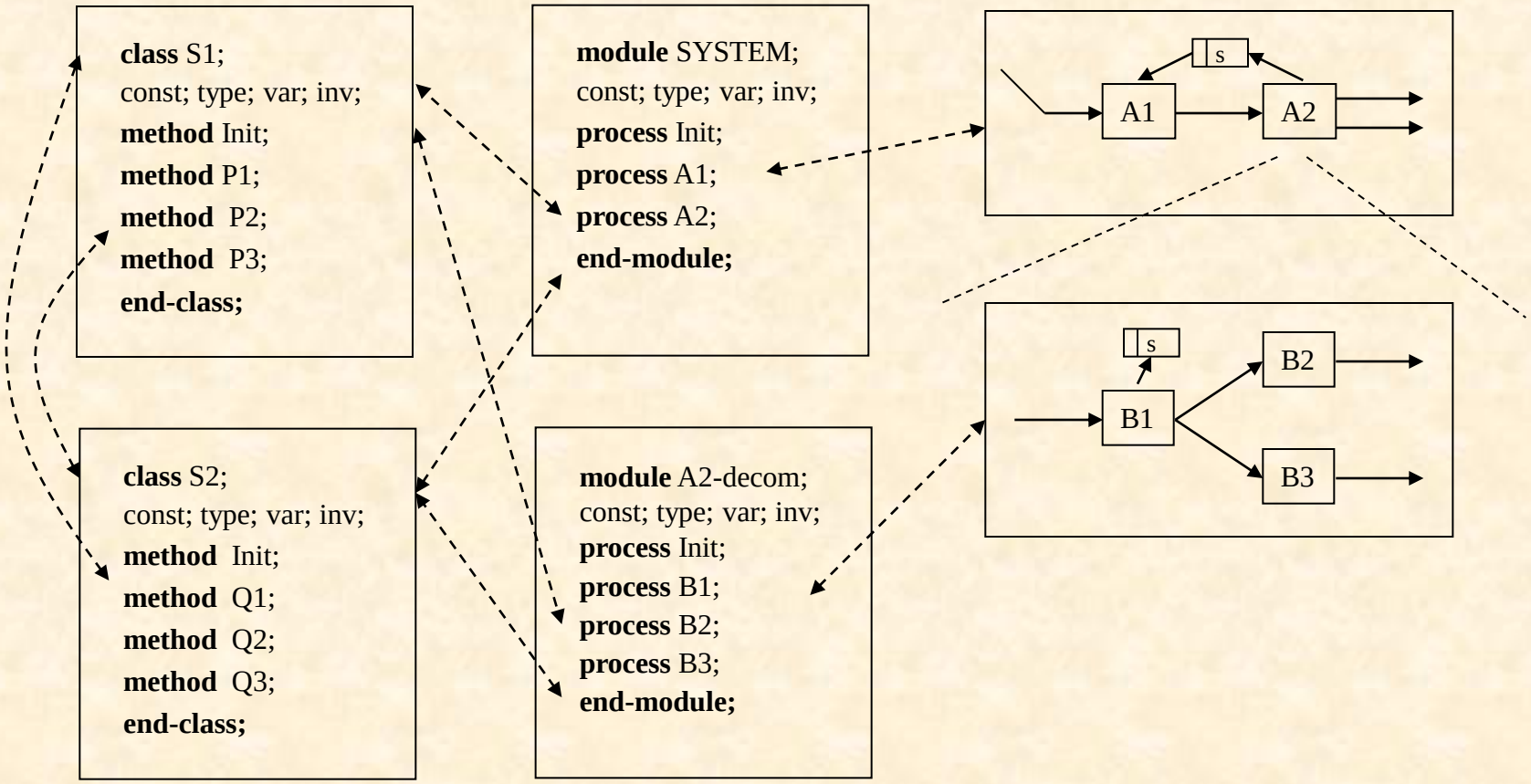
Three expected effects: improving understanding of requirements or designs, strengthening communication, and verifying/validating specifications.



SOFL: Structured Object-oriented Formal Language

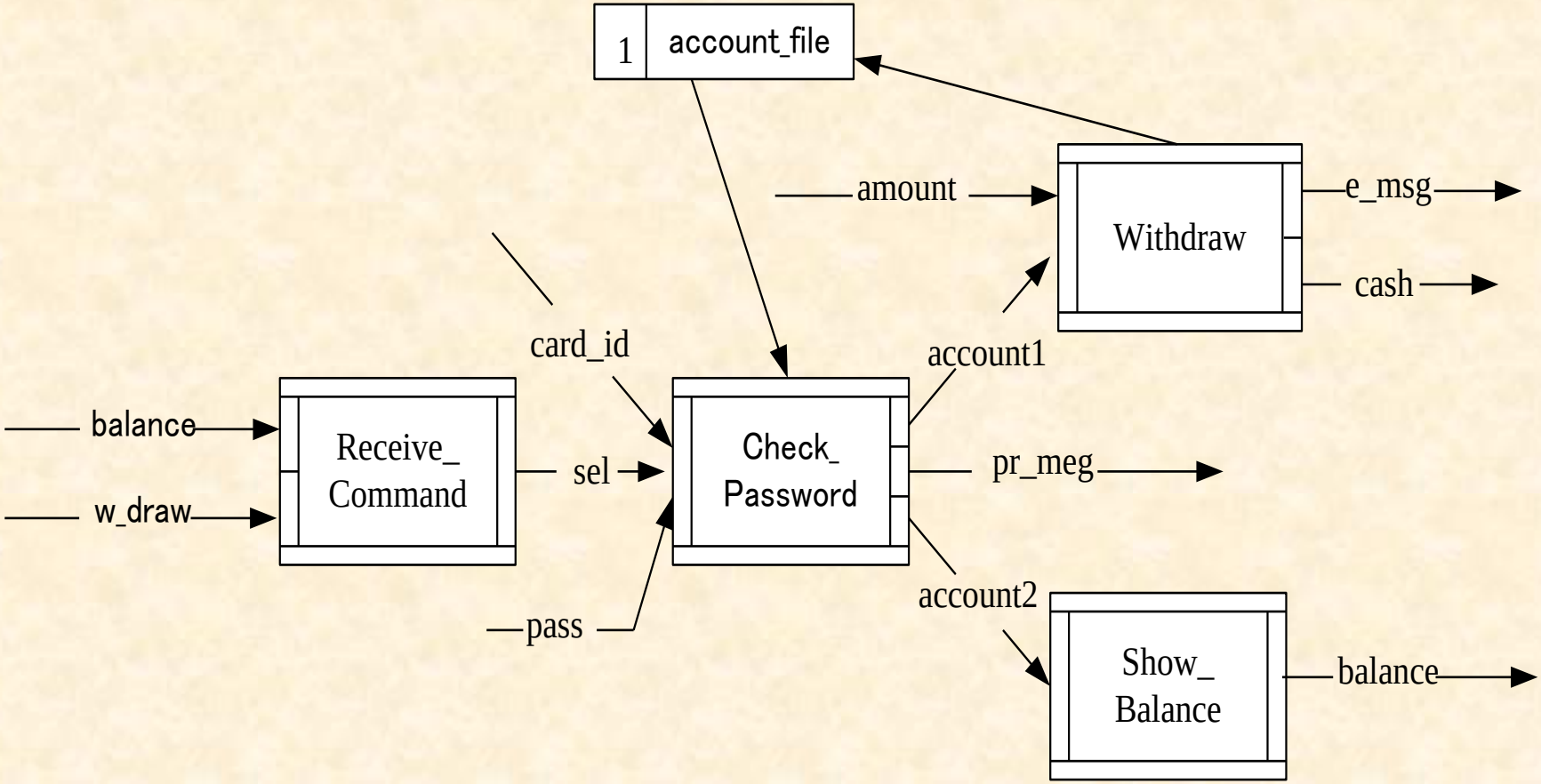
The structure of a SOFL specification:

CDFDs + modules + classes



Example:

A simplified ATM specification in SOFL:

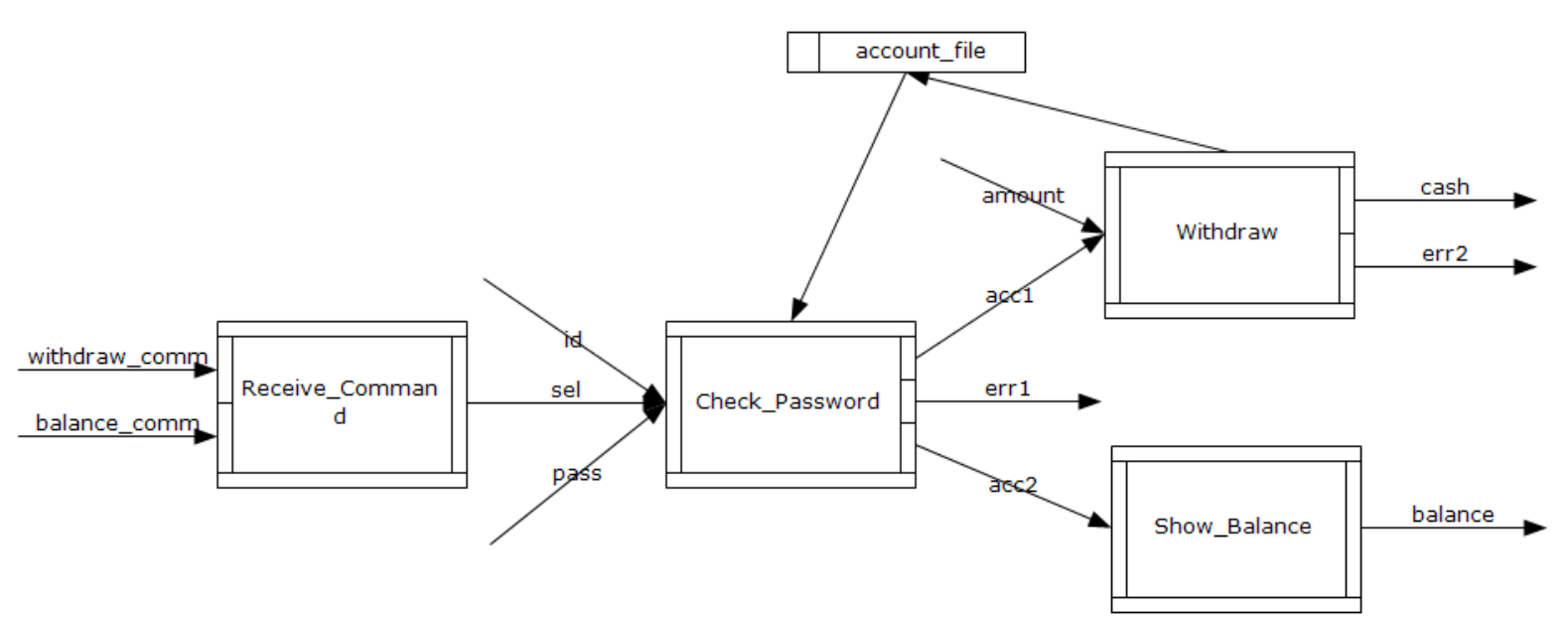


```
module SYSTEM_ATM;
   type
   Account = composed of
                    account_no: nat
                    password: nat
                    balance: real
                  end
var
   account_file: set of Account;
inv
    forall[x: account_file] | x.balance >= 0;

behav CDFD_No1;
...
```

```
process Withdraw(amount: real, account1: Account)
                        e_msg: string | cash: real
 ext wr account_file: set of Account
 pre account1 inset account_file
 post if amount <= account1.balance
        then
          cash = amount and
          let Newacc =
              modify(account1, balance -> account1.balance – amount)
           in
            account_file = union(diff(~account_file, {account1}), {Newacc})
       else
         e_meg = "The amount is over the limit. Reenter your amount.")
comment
…
end_process;
end_module
```

Basic idea of SOFL specification animation for verification and validation



{withdraw_comm}[Receive_Command, Check_Password, Withdraw]{cash}
{withdraw_comm}[Receive_Command, Check_Password, Withdraw]{err2}
{withdraw_comm}[Receive_Command, Check_Password]{err1}
{withdraw_comm}[Receive_Command, Check_Password, Show_Balance]{balance}
{balance_comm}[Receive_Command, Check_Password, Withdraw]{cash}
{balance_comm}[Receive_Command, Check_Password, Withdraw]{err2}
{balance_comm}[Receive_Command, Check_Password]{err1}
{balance_comm}[Receive_Command, Check_Password, Show_Balance]{balance}

Testing-Based Animation Approach

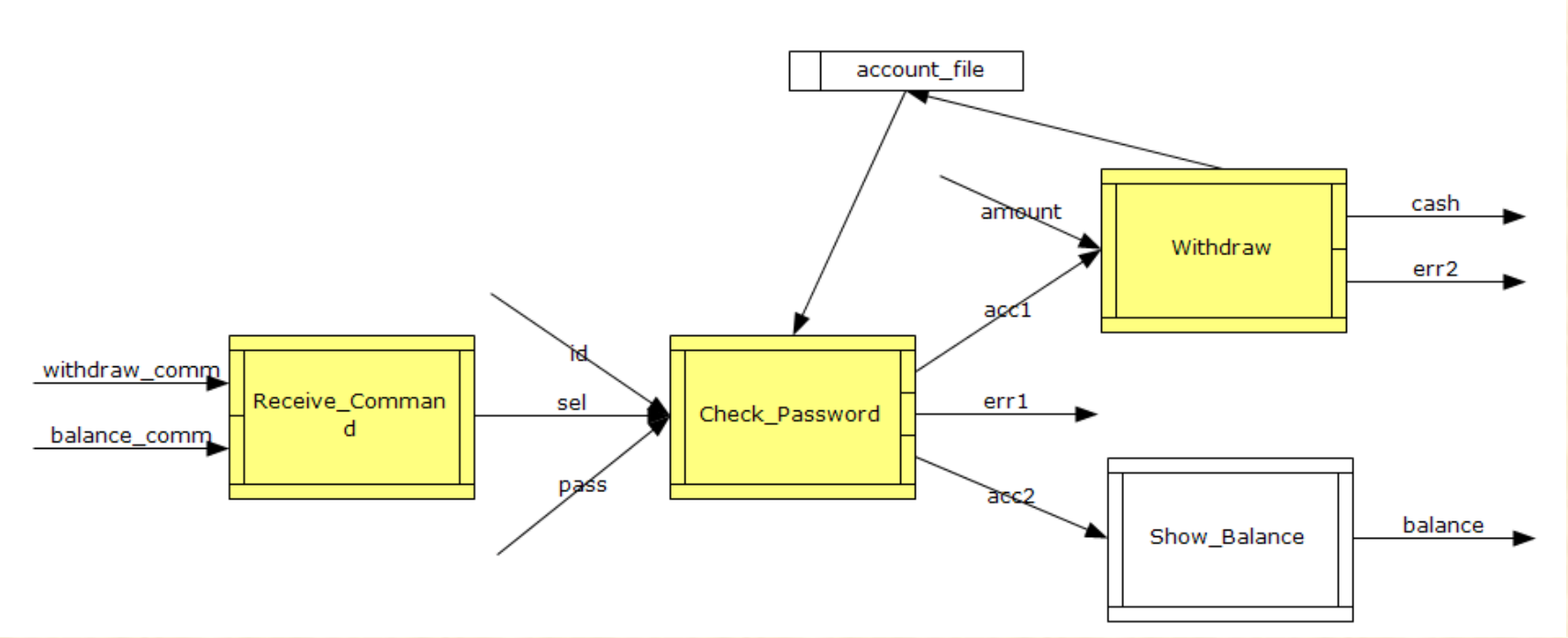
Steps of Animation:

Step1: Deriving system functional scenarios

Step2: Generating test cases

Step3: Carrying out animation for each scenario using the test cases.

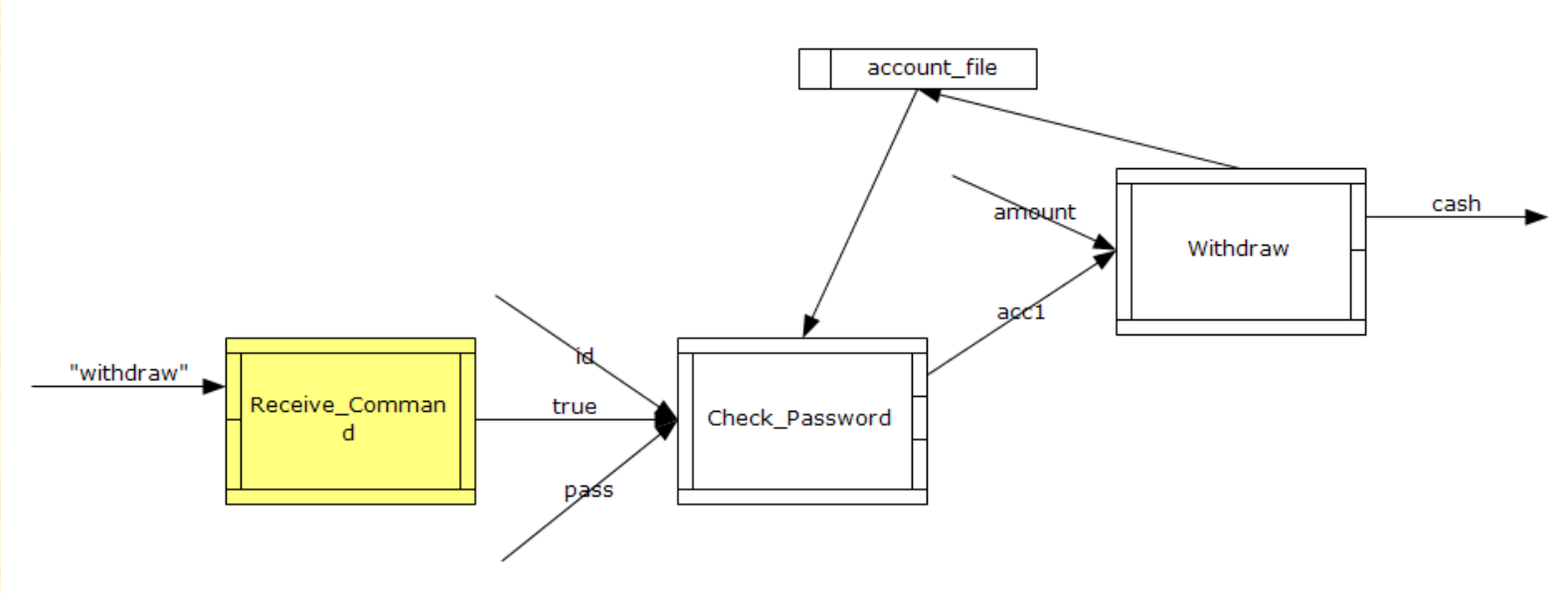
Animation of a single scenario



{withdraw_comm}[Receive_Command11, Check_Password11, Withdraw11]{cash}

Process	Input Variables	Input Data	Output Variables	Output Data
Received_Command$_{11}$	{withdraw_comm}	{"withdraw"}	{sel}	{true}
Check_Password$_{11}$	{sel, id, pass, ~Account_file}	{true, 0001, 1111, (0001, "Jack", 1111, 15000)}	{acc1}	{(0001, "Jack", 1111, 15000)}
Withdraw$_{11}$	{acc1, amount}	{(0001, "Jack", 1111, 15000), 5000}	{cash, Account_file}	{5000, (0001, "Jack", 1111, 10000)}

Animation of a single scenario



{withdraw_comm}[Receive_Command11, Check_Password11, Withdraw11]{cash}

Process	Input Variables	Input Data	Output Variables	Output Data
Received_Command$_{11}$	{withdraw_comm}	{"withdraw"}	{sel}	{true}
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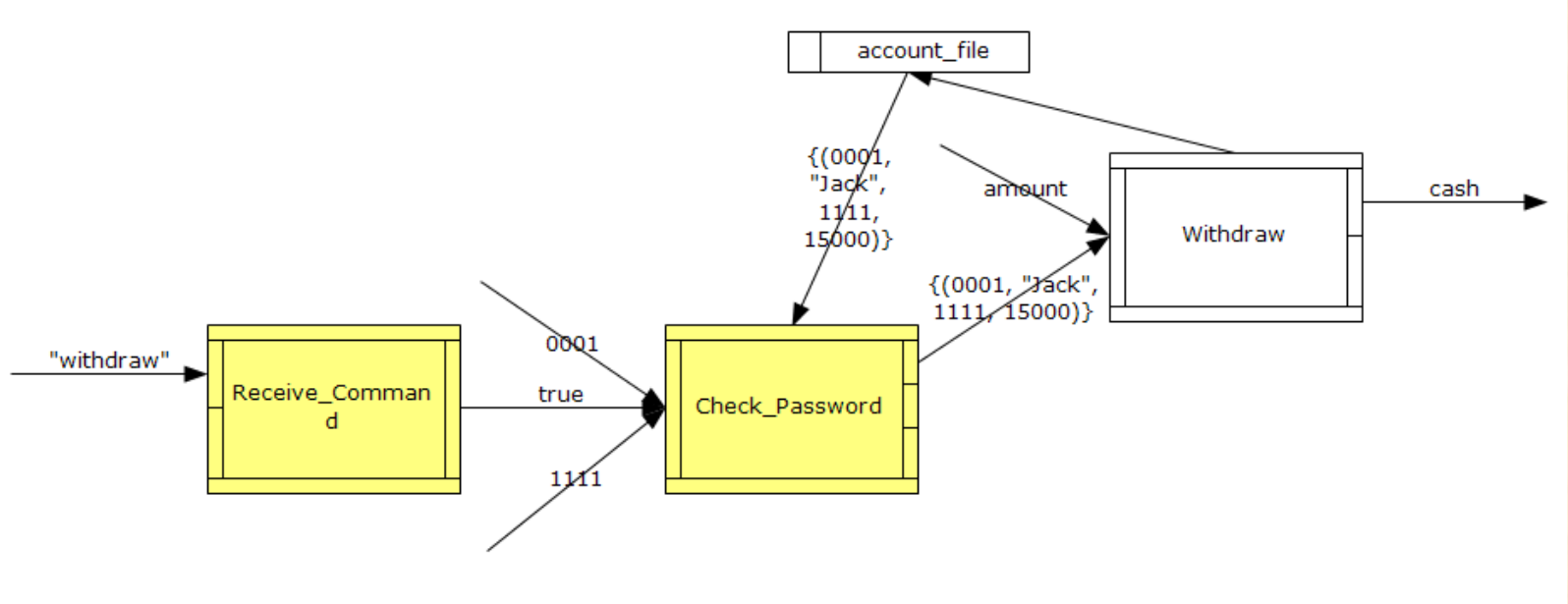
Withdraw$_{11}$	{acc1, amount}	{(0001, "Jack", 1111, 15000), 5000}	{cash, Account_file}	{5000, (0001, "Jack", 1111, 10000)}

Animation of a single scenario



{withdraw_comm}[Receive_Command11, Check_Password11, Withdraw11]{cash}

Process	Input Variables	Input Data	Output Variables	Output Data
Received_Command$_{11}$	{withdraw_comm}	{"withdraw"}	{sel}	{true}
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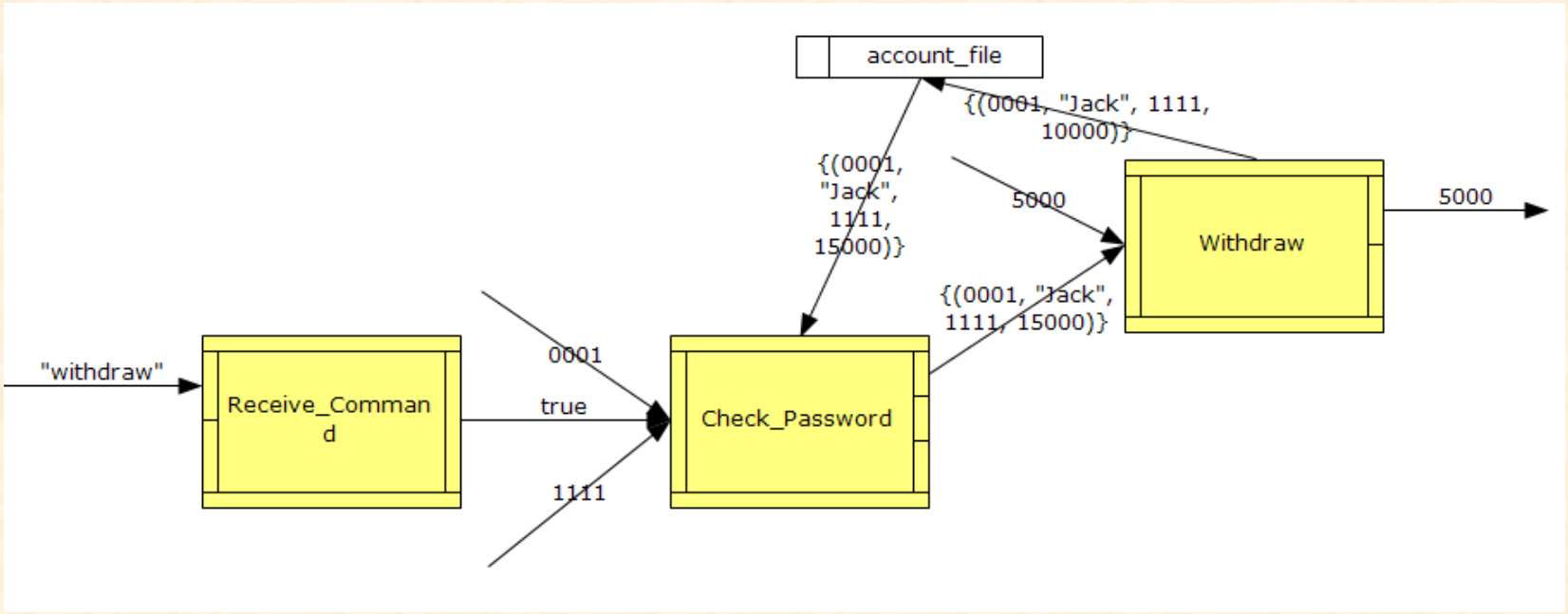
Withdraw$_{11}$	{acc1, amount}	{(0001, "Jack", 1111, 15000), 5000}	{cash, Account_file}	{5000, (0001, "Jack", 1111, 10000)}

Animation of a single scenario



{withdraw_comm}[Receive_Command11, Check_Password11, Withdraw11]{cash}

Process	Input Variables	Input Data	Output Variables	Output Data
Received_Command$_{11}$	{withdraw_comm}	{"withdraw"}	{sel}	{true}
Check_Password$_{11}$	{sel, id, pass, ~Account_file}	{true, 0001, 1111, (0001, "Jack", 1111, 15000)}	{acc1}	{(0001, "Jack", 1111, 15000)}
Withdraw$_{11}$	{acc1, amount}	{(0001, "Jack", 1111, 15000), 5000}	{cash, Account_file}	{5000, (0001, "Jack", 1111, 10000)}

Test case generation for processes (operations)

A test case is composed of a test datum and the corresponding expected result.

A specific method for test case generation

Functional Scenario-Based Test Case Generation:

a strategy for “divide and conquer”

Overall idea:

process A(x: int) y: int

pre x > 0

post (x > 10 => y = x + 1) and

(x <= 10 => y = x – 1)

end_process

Derivation

Functional scenario:

$A_{pre} \wedge G_i \wedge D_i$

(i=1,…,n)

f_1
f_2
…
f_n

A set of functional scenarios

Definition (FSF): Let

$S_{post} \equiv (G_1 \wedge D_1) \vee (G_2 \wedge D_2) \vee \cdots \vee (G_n \wedge D_n)$,

where G_i is a guard condition and

D_i is a defining condition, $i = 1,\ldots,n$.

Then, a functional scenario form (FSF) of S is:

$(S_{pre} \wedge G_1 \wedge D_1) \vee (S_{pre} \wedge G_2 \wedge D_2) \vee \cdots \vee (S_{pre} \wedge G_n \wedge D_n)$

where

$f_i = S_{pre} \wedge G_i \wedge D_i$ is called a

functional scenario (for generating test cases)

Test case generation criterion:

Let operation S have an FSF :
$(S_{pre} \wedge G_1 \wedge D_1) \vee (S_{pre} \wedge G_2 \wedge D_2) \vee \cdots \vee (S_{pre} \wedge G_n \wedge D_n)$, where $(n \geq 1)$.

Let T be a test set for S. Then, T must satisfy the condition
$(\forall i \in \{1,...,n\} \exists t \in T \cdot S_{pre}(t) \wedge G_i(t) \wedge D_i(t)))$ and
$\exists t \in T \cdot \neg S_{pre}(t)$

where $\neg$ Spre(t) describes an exceptional situation.

Example

A process specification in SOFL:

```
process ChildTicketDiscount(a: int, np: int) ap: int
pre a > 0 and np > 1
post (a > 12 => ap = np)  and
        (a <= 12 => ap = np – np * 0.5)
end_process
```

where a = age, ap = actual price, np =normal price

Two functional scenarios and one exception can be derived from this formal specification:

(1) a > 0 and np > 1 and a > 12 and ap = np

(2) a >0 and np > 1 and a <= 12 and

ap = np – np * 0.5

(3) a <= 0 or np <= 1 and anything

where anything means that anything can happen when the pre-condition is violated.

Test case generation

Test cases satisfying functional scenarios:

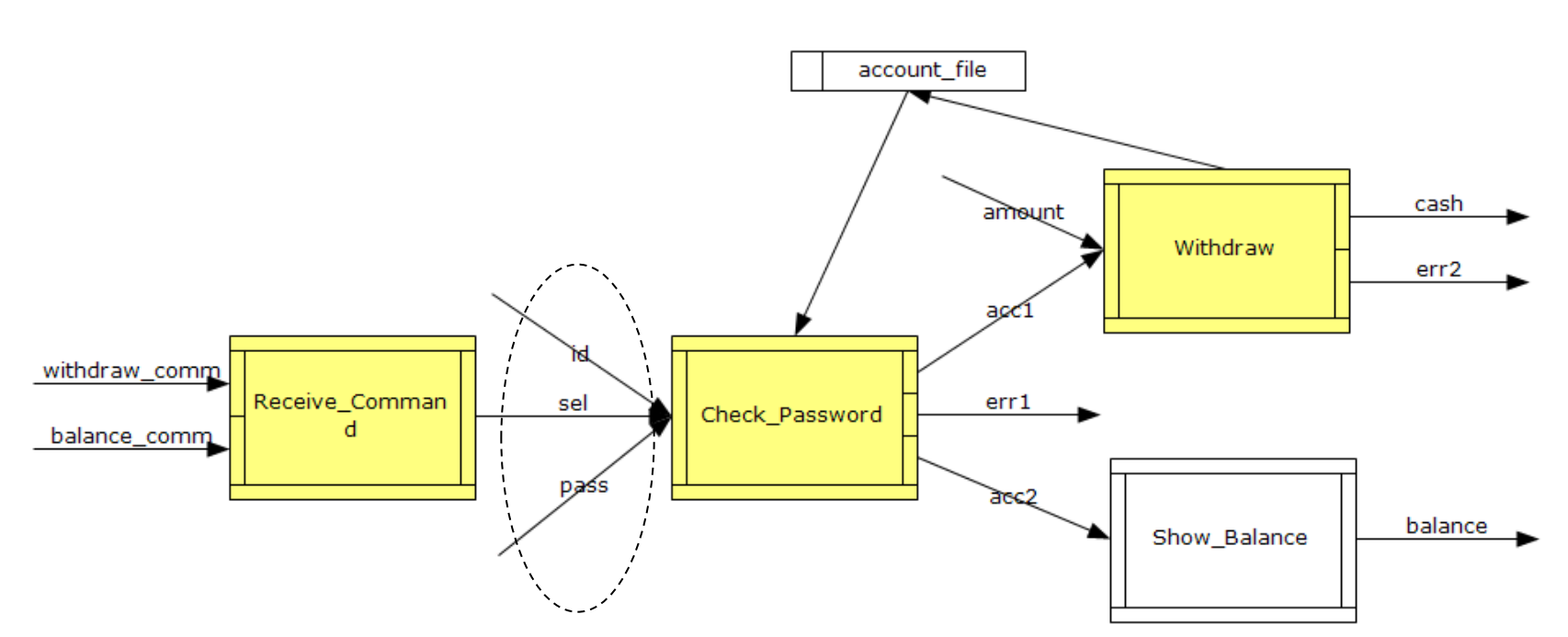
t1 = {(a, 15), (np, 100), (ap, 100)}

t2 = {(a, 10), (np, 100), (ap, 50)}

Test case violating the pre-condition (exceptional test case):

t3 = {(a, 0), (np, 200), (ap, 100)}

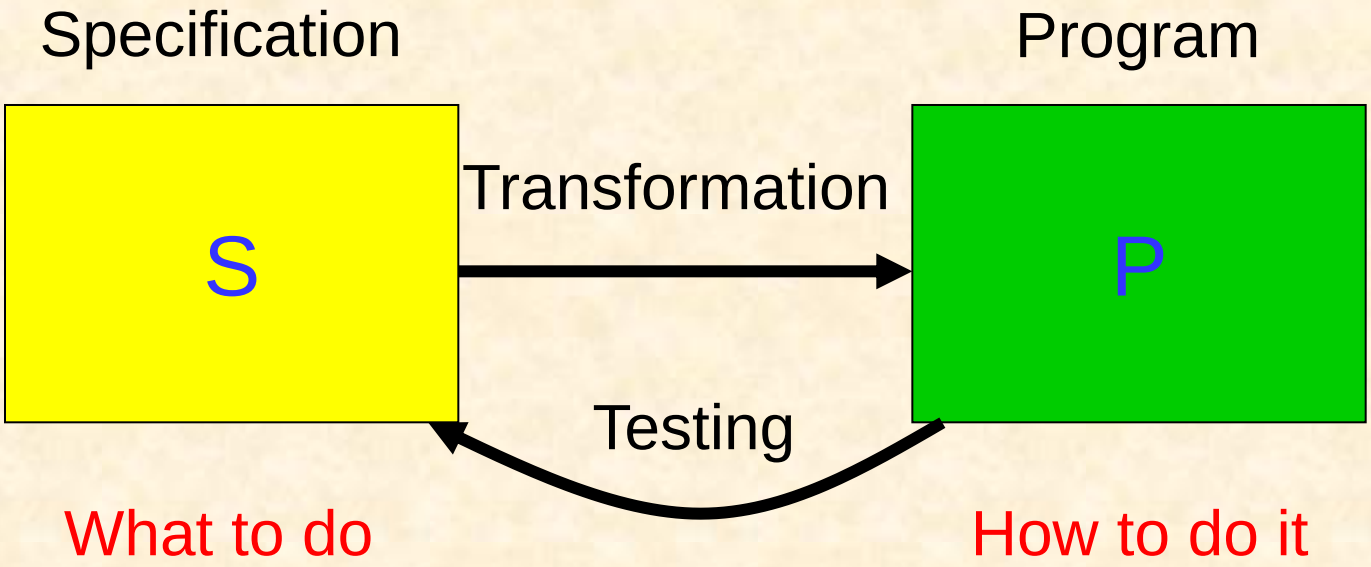
Test case generation within a system functional scenario



{withdraw_comm}[Receive_Command11, Check_Password11, Withdraw11]{cash}

Process	Input Variables	Input Data	Output Variables	Output Data
Received_Command$_{11}$	{withdraw_comm}	{"withdraw"}	{sel}	{true}
Check_Password$_{11}$	{sel, id, pass, ~Account_file}	{true, 0001, 1111, (0001, "Jack", 1111, 15000)}	{acc1}	{(0001, "Jack", 1111, 15000)}
Withdraw$_{11}$	{acc1, amount}	{(0001, "Jack", 1111, 15000), 5000}	{cash, Account_file}	{5000, (0001, "Jack", 1111, 10000)}

4. Specification-Based Program Testing and Inspection



Goal of testing: $S \sqsubseteq P$

P is a refinement of S

Steps of Specification-Based Testing

Three steps:

No. 1 Generate test cases based on the specification (reuse the test cases generated for specification animation)

No. 2 Run the program with the test cases.

No. 3 Analyze test results to determine whether the program contains bugs.

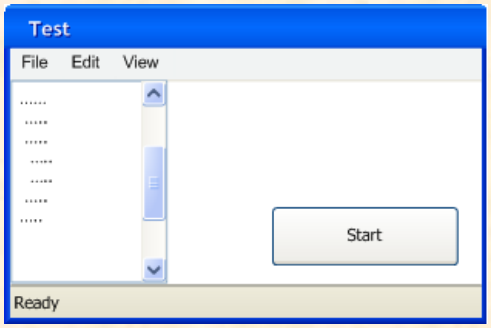
Test Strategy

① Ensure that all of the representative program paths are traversed.

② Ensure that all of the traversed program paths are correct.

Ideal Effect of the Testing

Press a Button



Adequate test cases

	x	y	z
case1	3	5	2
case2	0	4	9
case3	9	3	35
……			
……			

```
Method(int x, int y, int z){
int w;
if(x < y)
{
  w = y/x;
  while(w < z)
  {
    …
  }
} else
  …
}
}
```

Next

Techniques for implementing the test strategy

① Effective methods for test case generation based on formal specifications.

② Combination of functional scenario-based testing and inspection.

③ Combination of functional scenario-based testing and Hoare logic

① Effective methods for test case generation based on formal specifications.

A) Functional scenario-based test case generation method

B) “Vibration” test case generation method

Scenario-based testing: a strategy for ``divide and conquer”

Specification (in SOFL)

```
process A(x: int) y: int
pre   x > 0
post (x > 10 => y = x + 1) and
       (x <= 10 => y = x – 1)
end_process
```

Program

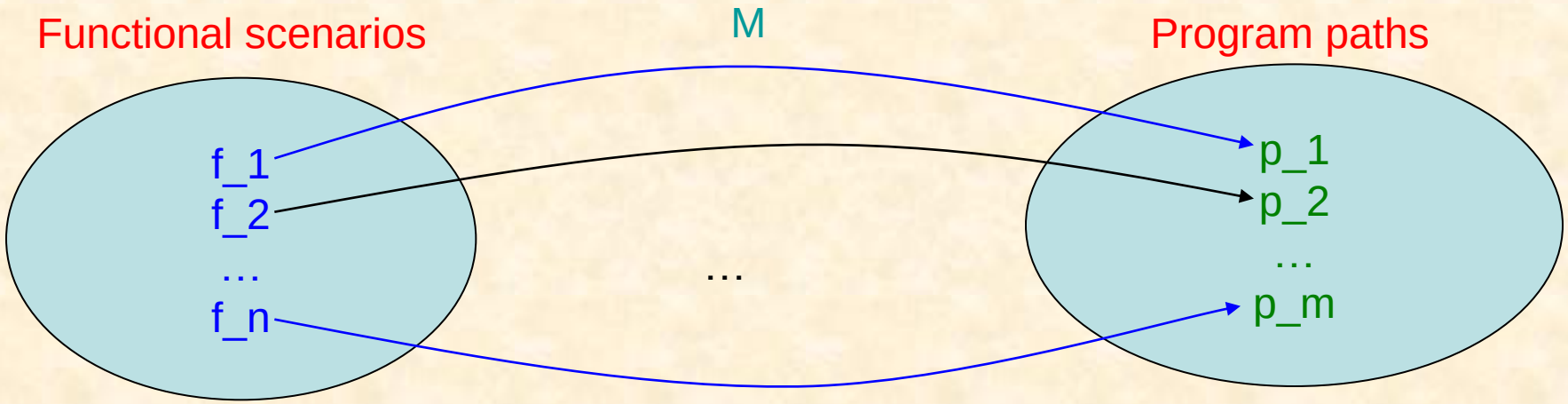
```
int A(int x) {
If (x > 0) {
 if (x > 10)  y := x * 1;
 else  y := x – 1;
 return y; }
else System.out.println(“the
       pre is violated”)  }
```

Satisfy?

Functional scenario:

$A_{pre} \wedge G_i \wedge D_i$

(i=1,…,n)

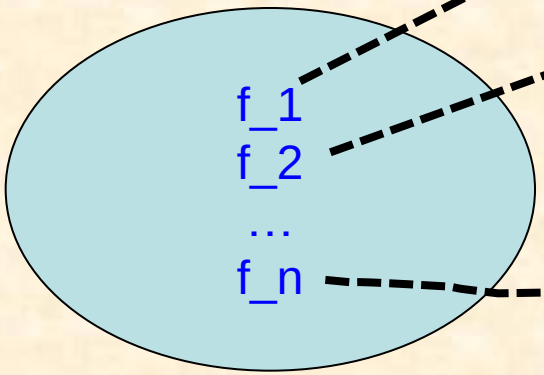


Specification:

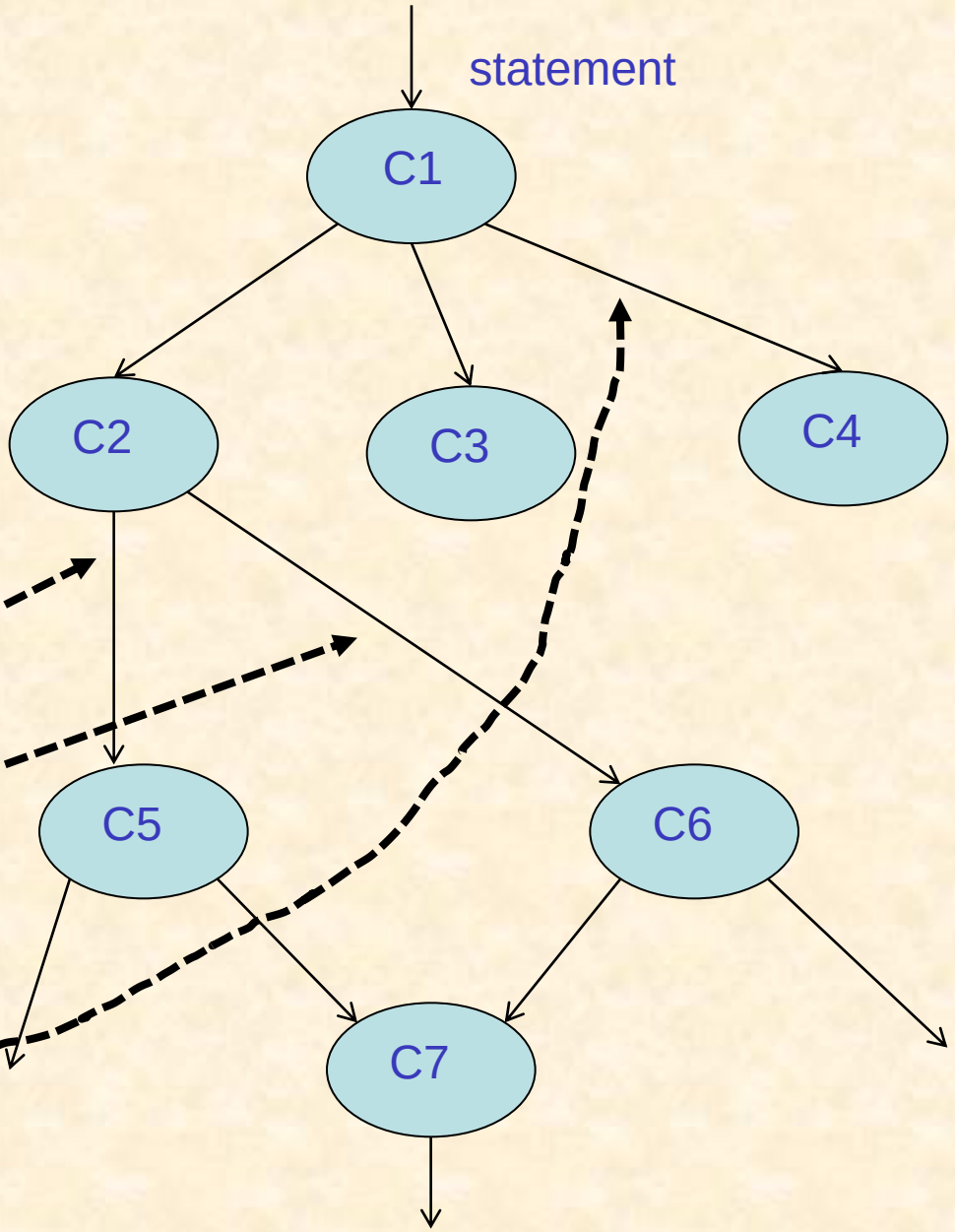
```
process A(x: int) y: int
pre   x > 0
post (x > 10 => y = x + 1) and
       (x <= 10 => y = x – 1)
end_process
```

Derivation

Functional scenarios



Program:



Definition (FSF): Let

$S_{post} \equiv (G_1 \wedge D_1) \vee (G_2 \wedge D_2) \vee \cdots \vee (G_n \wedge D_n)$,

where G_i is a guard condition and

D_i is a defining condition, $i = 1,\ldots,n$.

Then, a functional scenario form (FSF) of S is:

$(S_{pre} \wedge G_1 \wedge D_1) \vee (S_{pre} \wedge G_2 \wedge D_2) \vee \cdots \vee (S_{pre} \wedge G_n \wedge D_n)$

where

$f_i = S_{pre} \wedge G_i \wedge D_i$ is called a functional scenario

$S_{pre} \wedge G_i$ is called a test condition

Test case generation criterion:

Let operation S have an FSF :
$(S_{pre} \wedge G_1 \wedge D_1) \vee (S_{pre} \wedge G_2 \wedge D_2) \vee \cdots \vee (S_{pre} \wedge G_n \wedge D_n)$, where $(n \geq 1)$.

Let T be a test set for S. Then, T must satisfy the condition
$(\forall i \in \{1,...,n\} \exists t \in T \cdot S_{pre}(t) \wedge G_i(t)))$ and
$\exists t \in T \cdot \neg S_{pre}(t)$

where $\neg$ Spre(t) describes an exceptional situation.

Test oracle for test result analysis in the scenario-based testing

Definition: Let **$S_{pre} \wedge G \wedge D$** be a functional scenario and **T** be a test set generated from its test condition **$S_{pre} \wedge G$.** If the condition

$$\exists t \in T \cdot S_{pre}(t) \wedge G(t) \wedge \neg D(t, P(t))$$

holds, it indicates that a bug in program P is found by t (also by T).

A “Vibration” method for test set generation

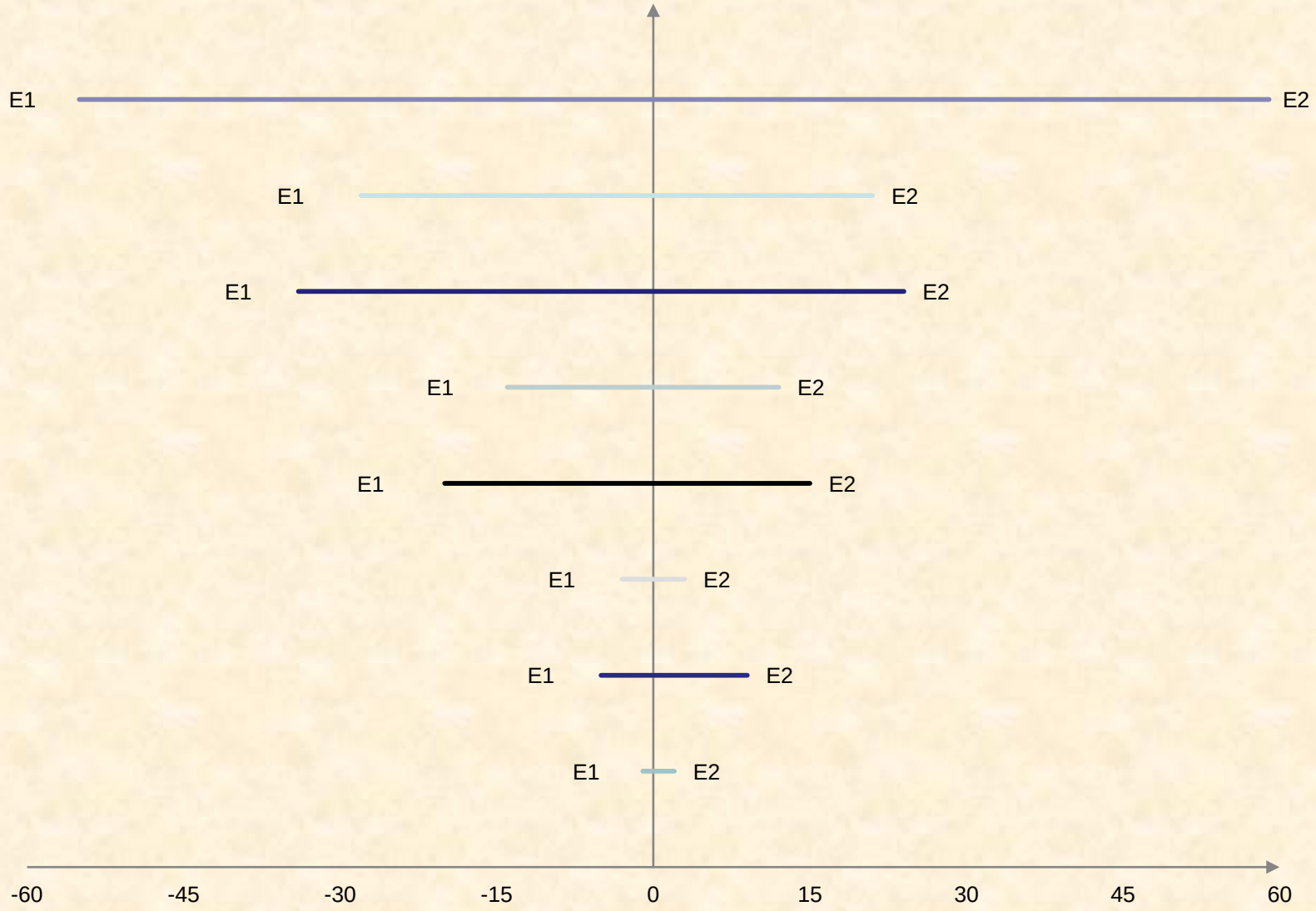
Let $E_1(x_1,x_2,...,x_n)$ R $E_2(x_1,x_2,...,x_n)$ denote that expressions E_1 and E_2 have relation R, where $x_1,x_2,...,x_n$ are all input variables involved in these expressions.

Question: how can test cases be generated based on the relation so that they can quickly cover all of the paths implementing the functional scenario involving the relation in the specification?

V-Method:

We first produce values for $x_1,x_2,\ldots,x_n$ such that the relation $E_1(x_1,x_2,\ldots,x_n)$ R $E_2(x_1,x_2,\ldots,x_n)$ holds with an initial "distance" between E_1 and E_2, and then repeatedly create more values for the variables such that the relation still holds but the "distance" between E_1 and E_2 "vibrates" (changes repeatedly) between the initial "distance" and the maximum "distance".

Example: E1 > E2



(2) Combination of functional scenario-based testing and inspection.

Step 1: Generate a test case.

Step 2: Execute the program to obtain a traversed path.

Step 3: Inspect the traversed path based on the corresponding functional scenario in the specification.

Example

```
process ChildTicketDiscount(a: int, np: int) ap: int
pre a > 0 and np > 1
post (a > 12 => ap = np)  and
       (a <= 12 => ap = np – np * 0.5)
end_process
```

Two functional scenarios and one exception:

(1) a > 0 and np > 1 and a > 12 and ap = np

(2) a >0 and np > 1 and a <= 12 and

ap = np – np * 0.5

(3) a <= 0 or np <= 1 and anything (exception)

Implementation of the specification

```
int ChildTicketDiscount(int a, int np) {
 (1)   If (a > 0 && np > 1) {
 (2)    if (a > 12)
 (3)       ap := np;
 (4)    else ap := np ** 2 – np – np * 0.5;
 (5)    return ap;}
 (6)   else System.out.println(``the
                          precondition is violated.”)
}
```

Test case and test result

test case: a = 5, np = 2

test condition: a > 0 and np > 1 and a <= 12

functional scenario: a > 0 and np > 1 and
a <= 12 and ap = np – np * 0.5

traversed program path:

[(1)(2)′(4)(5)]

That is:

(1) a > 0 && np > 1)

(2)’ a <= 12

(4) ap := np ** 2 – np – np * 0.5

(5) return ap

Checklist derived from the functional scenario:

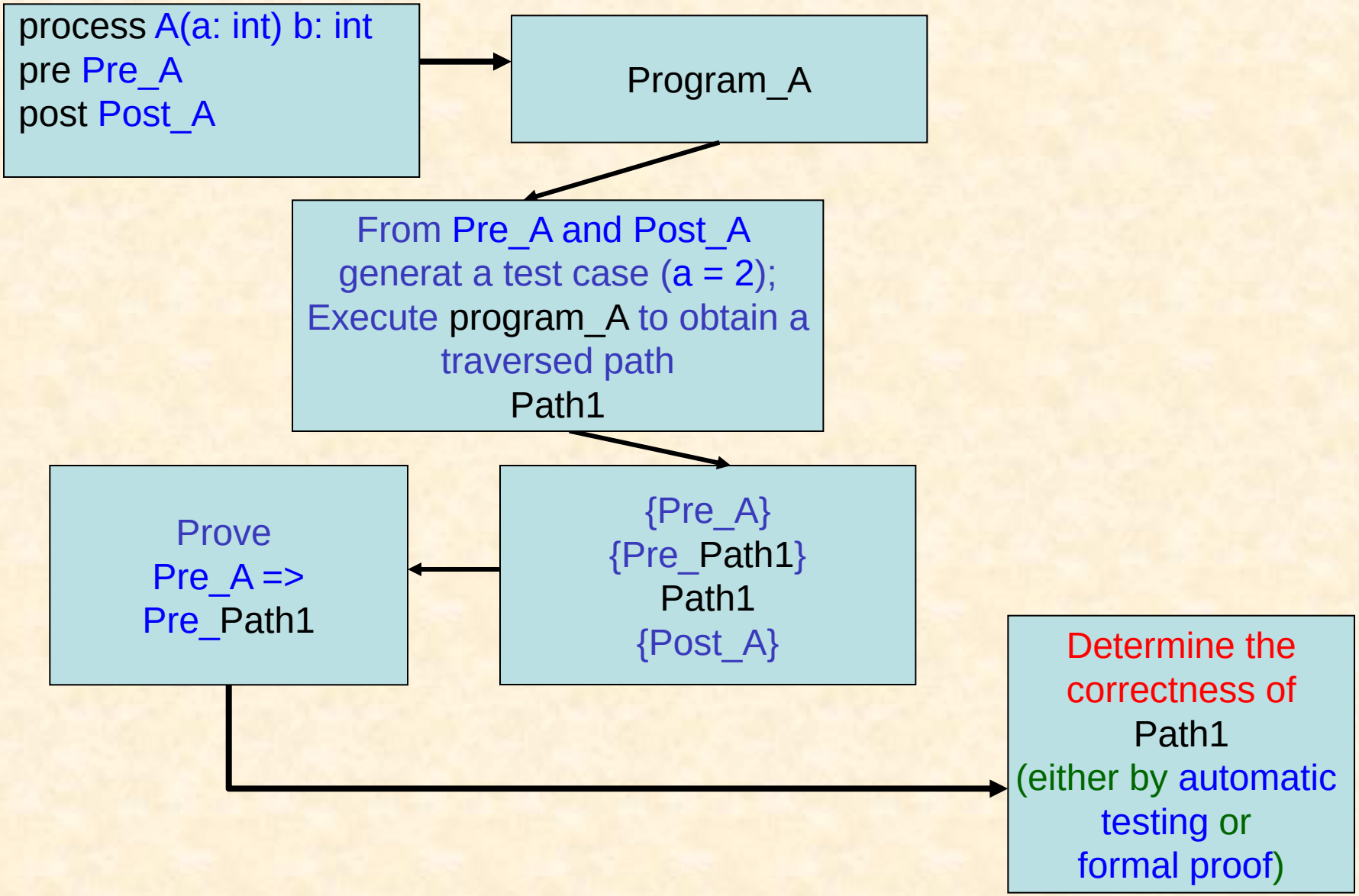
(1) Is the pre-condition a > 0 and np > 1 implemented correctly?

(2) Is the guard condition a <= 12 implemented correctly?

(3) Is the defining condition ap = np – np * 0.5 implemented correctly?

By trying to answer the above questions, the traversed path can be inspected.

(3) Combination of functional scenario-based testing and Hoare logic:



Relevant axioms derived from Hoare logic:

(1) $\{Q(E/x)\}\ x := E\ \{Q\}$ (axiom for assignment)

(2) $\{Q\}\ S\ \{Q\}$ where S is one of the non-changing segments, such as the following two:

"return'' statement,

printing statement.

(3) $\{S \wedge Q\}\ S\ \{Q\}$ where S is a **decision**, **condition**, or **predicate expression**, which is used in an if-then-else statement or a while-loop.

Example

test case: a = 5, np = 2

test condition: a > 0 and np > 1 and a <= 12

functional scenario: a > 0 and np > 1 and
a <= 12 and ap = np – np ∗ 0.5

traversed program path:

[(1)(2)′(4)(5)]

output ap = 1

test result evaluation:

a > 0 and np > 1 and a <= 12 and not
ap = np – np ∗ 0.5 (false)

No bug is found in this test, although a bug exists on the path.

Step1: Form the path triple:

{a > 0 and np > 1}

[a > 0 && n_f > 1, a <= 12,

ap := np ** 2 – np – np * 0.5,

return ap]

{a <= 12 and ap = np - np * 0.5}

Step 2: Derive the asserted path by applying the axiom for assignment or non-change segments:

{a > 0 and np >1}
{a > 0 and np > 1 and
a <=12 and np ** 2 - np - np * 0.5 = np - np * 0.5} Derived pre-condition
a > 0 && np > 1
{a <= 12 and np** 2 – np – np * 0.5 = np - np * 0.5}
  a <= 12
{a <= 12 and np** 2 – np – np * 0.5 = np - np * 0.5}
  ap := np ** 2 – np – np * 0.5
{a <= 12 and ap = np - np * 0.5}
  return ap
{a <= 12 and ap = np - np * 0.5}

Step 3: Verify the validity of the implication:

a > 0 and np >1 =>
a > 0 and np > 1 and
a <=12 and
np ** 2 - np - np * 0.5 = np - np * 0.5

Methods for verification:

(1) Automatic testing (effective when the implication does not hold, but may not be effective to give a conclusion when the implication holds)

(2) Formal proof (effective when the implication holds, but full automation may be impossible)

Example of verification by testing

Let a = 1

np = 4.

Then, the implication becomes

(a > 0 and np >1)[1/a, 4/np] =>

(a > 0 and np > 1 and

a <=12 and

np ** 2 - np - np * 0.5 = np - np * 0.5)[1/a, 4/np]

Result: (true => false) <=> fase

5. Open Problems

(1) There is a lack of a theory and method for generating adequate test cases only based on specifications to cover all of the representative paths for any given program (necessary to consider both the program and specification structures, but how?)

(2) How to avoid human impact on the effectiveness of program inspection (automatic inspection?)

(3) How to deal with the program path explosion problem ?(when the program contains many nested conditional or iterative constructs)

6. Conclusions

(1) Specification animation can prevent errors and help set up a foundation for implementation and specification-based testing and inspection.

(2) Specification-based testing can be used to check automatically whether a program is consistent with its specification, but it needs review/inspection to enhance its effectiveness in reliability assurance.

(3) Integration of specification animation, testing, and inspection can help reduce time and cost in verification and validation.

7. Future Work

(1) Address the open problems mentioned previously.

(2) Explore techniques for full automation of the integrated method for verification and validation.

(3) Conduct experiments to evaluate the performance of the integrated method.

Thank You !