Guidelines for the Use of Function Block Diagram in Reactor Protection Systems

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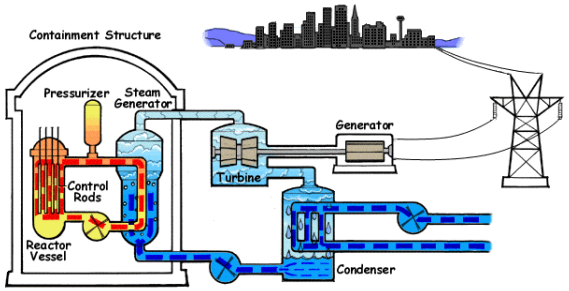
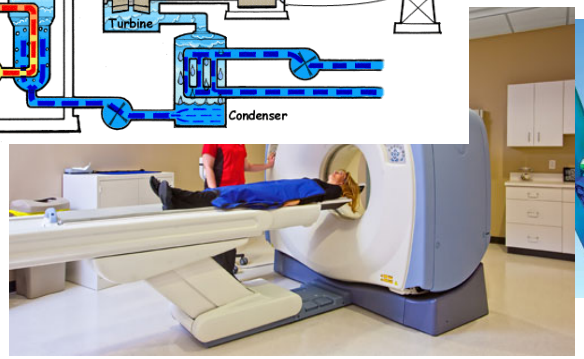
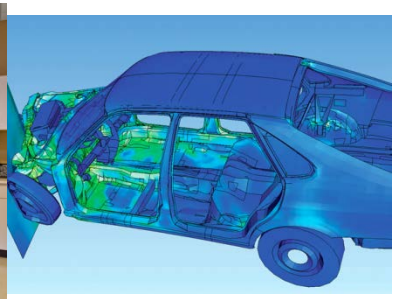
INTRODUCTION

Introduction

- Software in safety critical systems
  - Nuclear power plant
    - RPS (Reactor Protection System)
    - ESF-CCS (Engineering Safety Feature Component Control System)
  - Automotive systems
  - Medical systems
  - Etc.



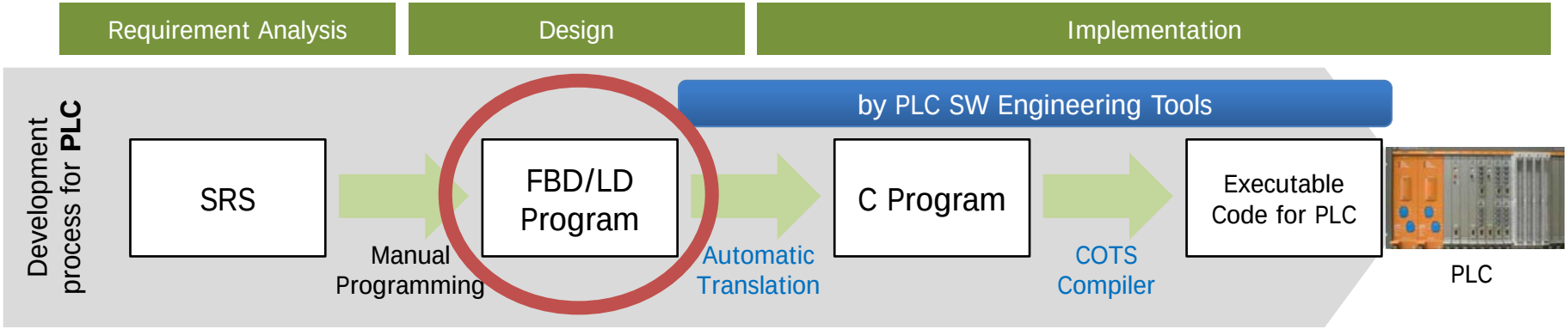




- Failure of the software
  - injuries to people, damages to the environment, or extensive economic losses
- Dependability of the software is important for SAFETY and PERMISSION.

Software development in the nuclear power plant domain

- Software requirement specification (natural language)
- Software design written in FBD/LD
- Software implementation by a software engineering tool

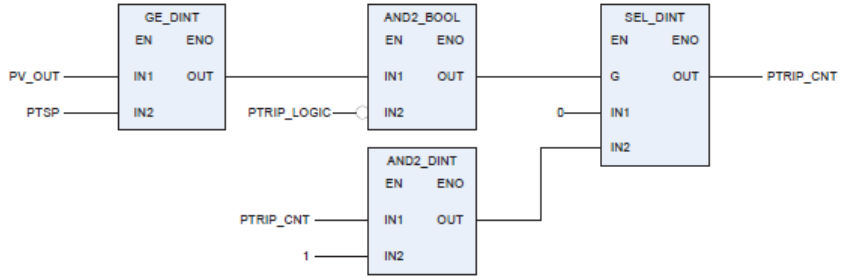


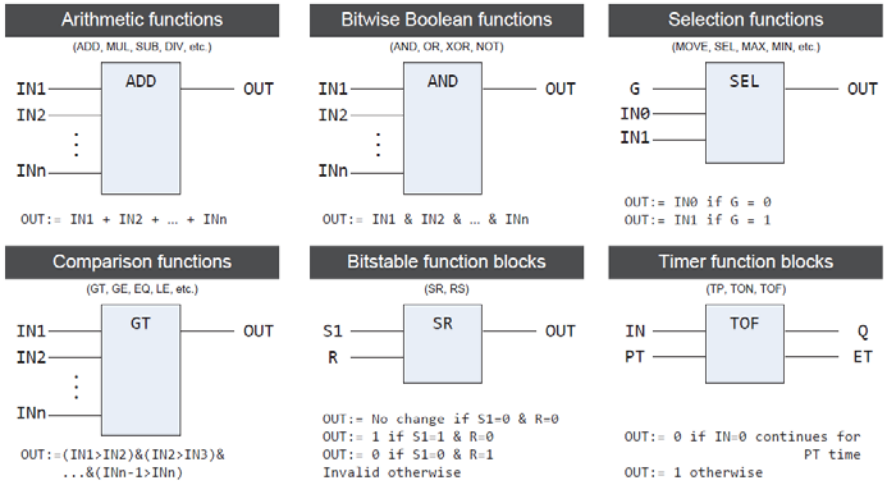
- pSET (POSAFE-Q Software Engineering Tool)
  - KNICS ARP-1400 (PLC)

BACKGROUND

Related Work – Function Block Diagram

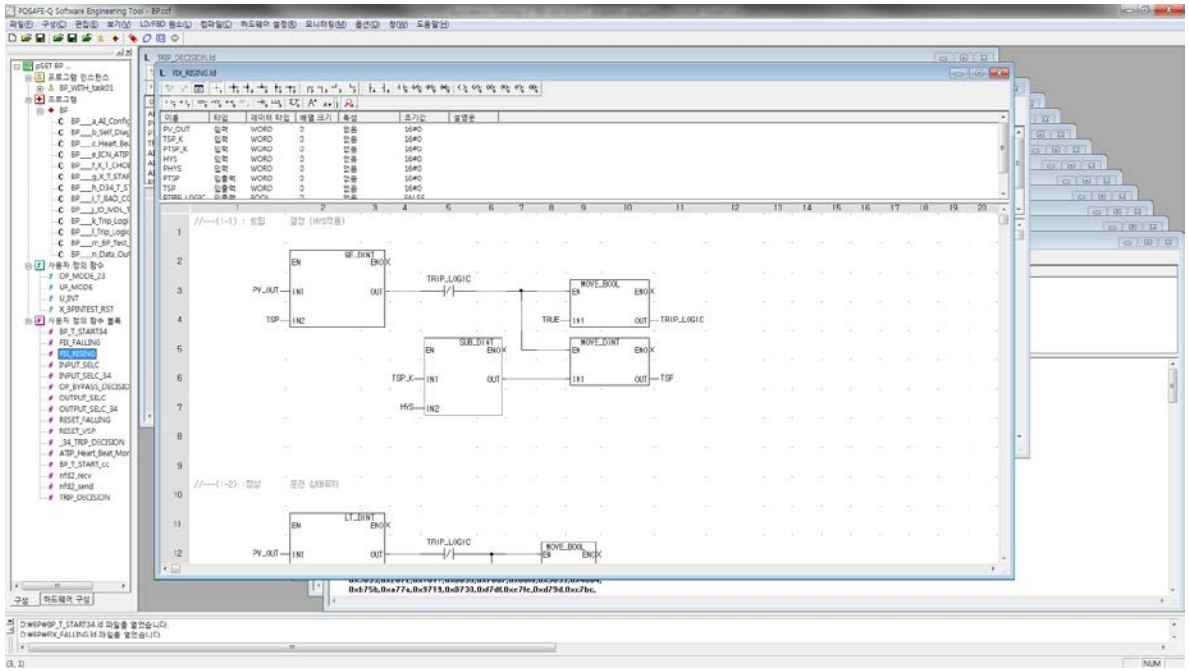
- International Standard IEC 61131-3
  - Programmable controllers – Part 3: Programming languages
  - IL, ST, LD, **FBD**, SFC
  - A graphical language





Introduction (cont'd)

- POSAFE-Q Software Engineering Tool (pSET)
  - Korea Nuclear Instrumentation & Control System R&D Center (KNICS)
- FBD and Ladder Diagram (LD) to design a software of POSAFE-Q Programmable Logic Controller (PLC)
- ANSI-C language to implement the design



Related Work – Dependable Programming

- A.k.a.
  - programming guidelines
  - safe programming

IEC 62304

MISRA-C/C++

- MISRA-C: Automotive industry
- DO-178B: Airborne systems
- NuREG/CR-6463: Nuclear domain
  - IEC 61131-3 programming language, c/c++, Ada, Pascal, PL/M

ISO 26262

NUREG/CR-6463

DO-178B/C

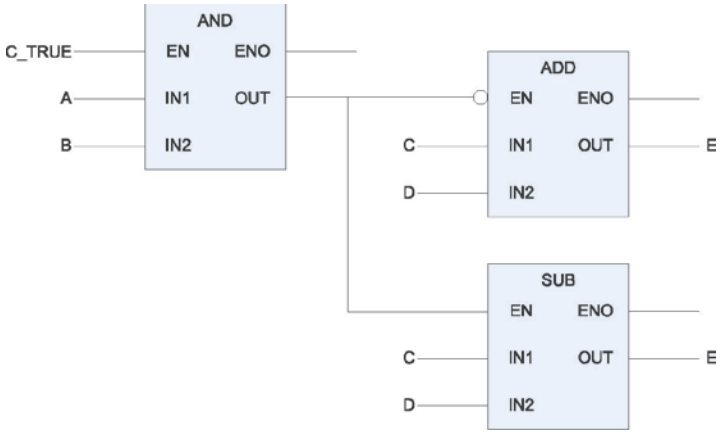
⋮

DEPENDABLE CASES FOR FBD PROGRAMS

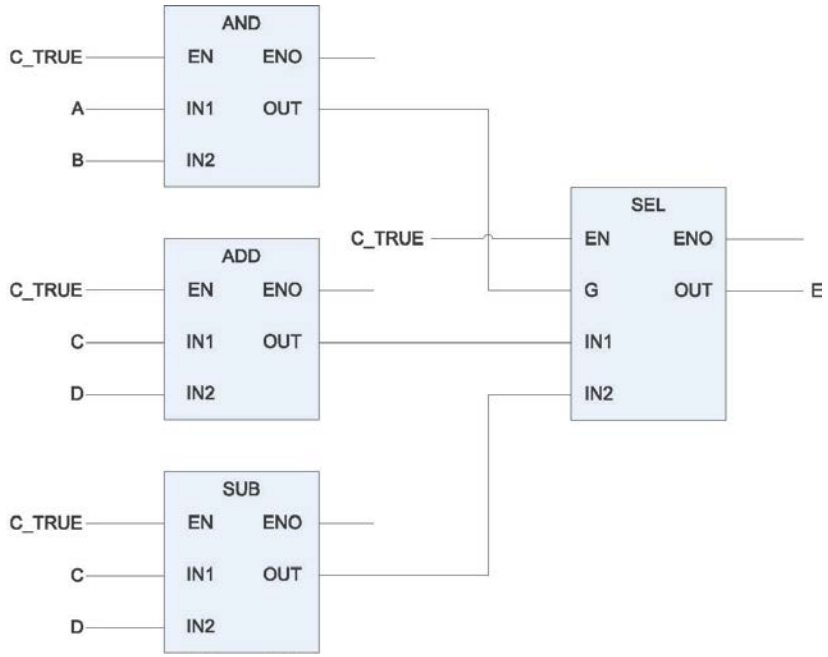
(1/5) Execution control except EN and ENO signals

- Boolean "EN" (Enable) input and "ENO" (Enable Out) output: Optional ports
- Control flows in data flow based language: NOT SUITABLE
- The output 'E' is not clear
- SOLUTION: Using selection blocks (SEL, MUX)

```
if (A&B) = FALSE then E := C + D
if (A&B) = TRUE  then E := C - D
```

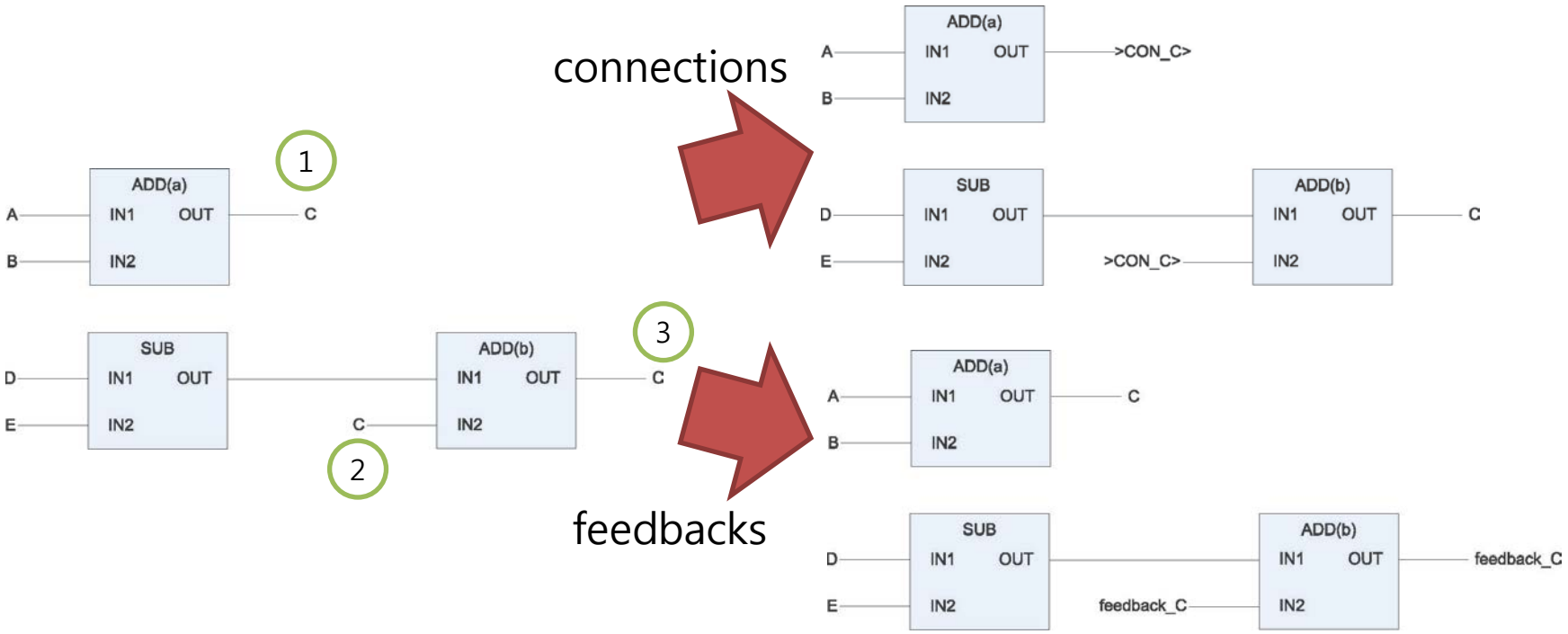



```
if G = FALSE then OUT := IN1 which IN1 = A + B
if G = TRUE  then OUT := IN2 which IN2 = A - B
```



(2/5) Usage of Output Variables

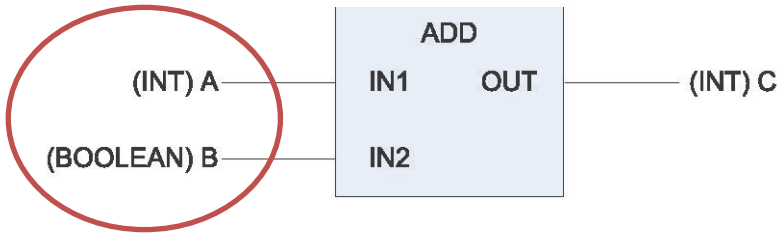
- One evaluation per one cycle
- Ambiguous connections: [①C to ②C] [③C - ②C]
- Overwriting problems: different values of 'C' in a cycle
- SOLUTION: clear connections using connector/continuation or feedback variables

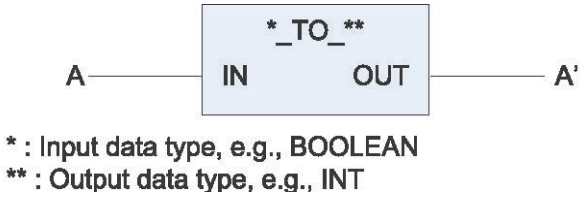


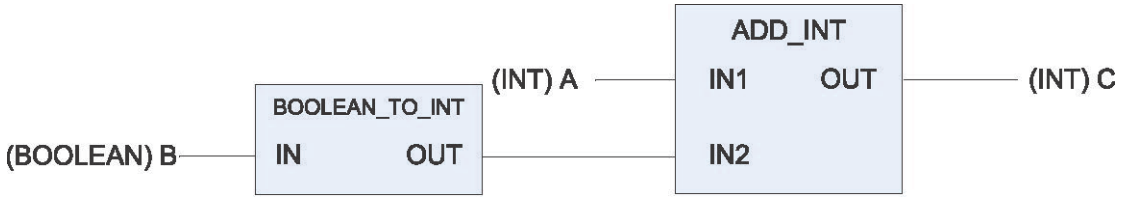
(3/5) Consensus of Data Type

- OVERLOADING is not a problem in FBD.
- Automatic type casting of target systems is a PROBLEM.

- SOLUTION
  - eliminate implicit type casting → use type conversion blocks
  - clarify a type of blocks

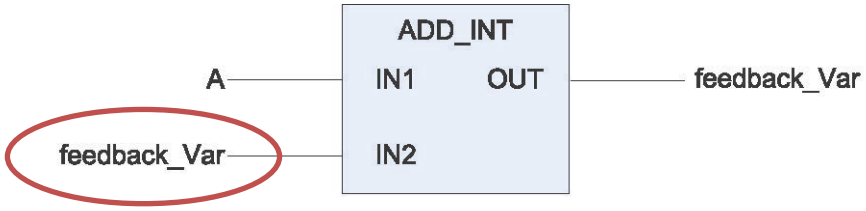






(4/5) Initialization of Feedback Variables

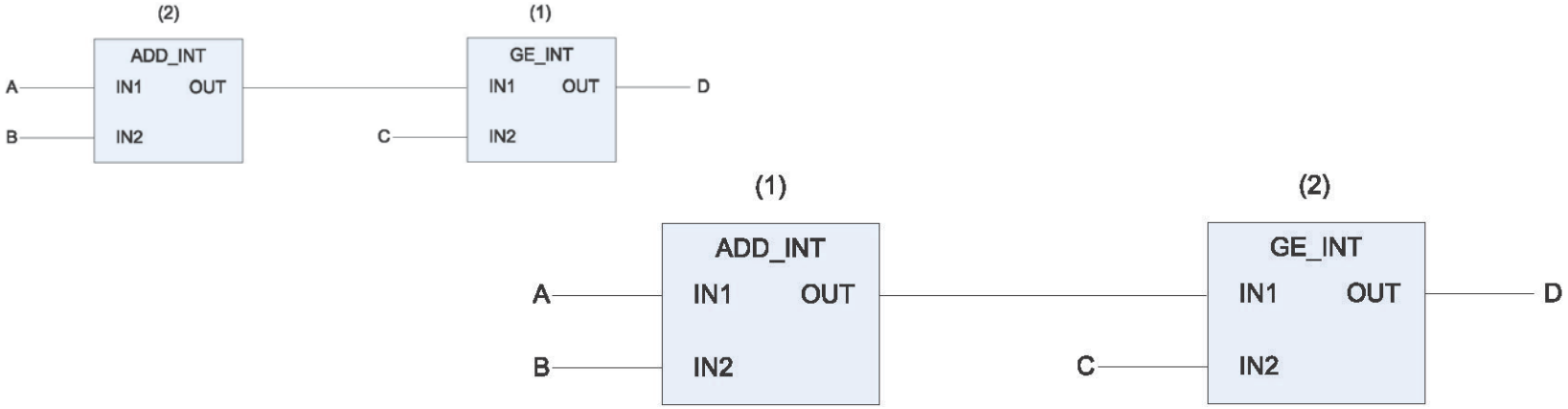
- Explicit initiation of all variables are not mandatory.
- Storable variables (i.e., feedback) MUST be initiated.
- No values in feedback variables at the beginning without initialization
- 3 mechanisms of initialization
  - the default initial value(s) of the underlying elementary data types as defined in IEC 61131-3;
  - NULL, if the variable is a reference;
  - or the user-defined value(s) of the variable; this value is optionally specified in the variable declaration.



(5/5) Explicit Order of Evaluation

- Labeled or displayed order ≠ EVALUATION ORDER (*mislabeled*)

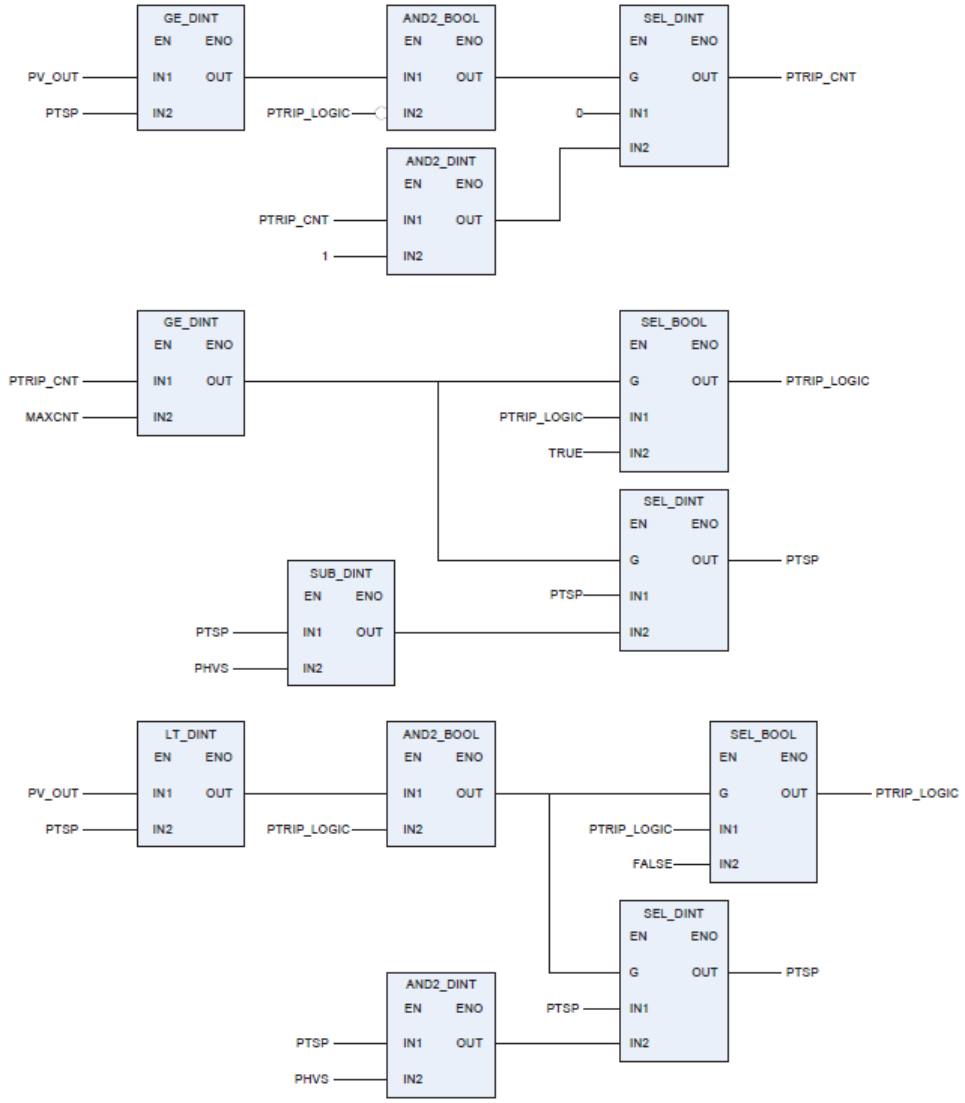
- Two solutions to eliminate the mislabeling:
  - programming without labeling order;
  - **programming with labeling order in the same order of evaluation**



CASE STUDY

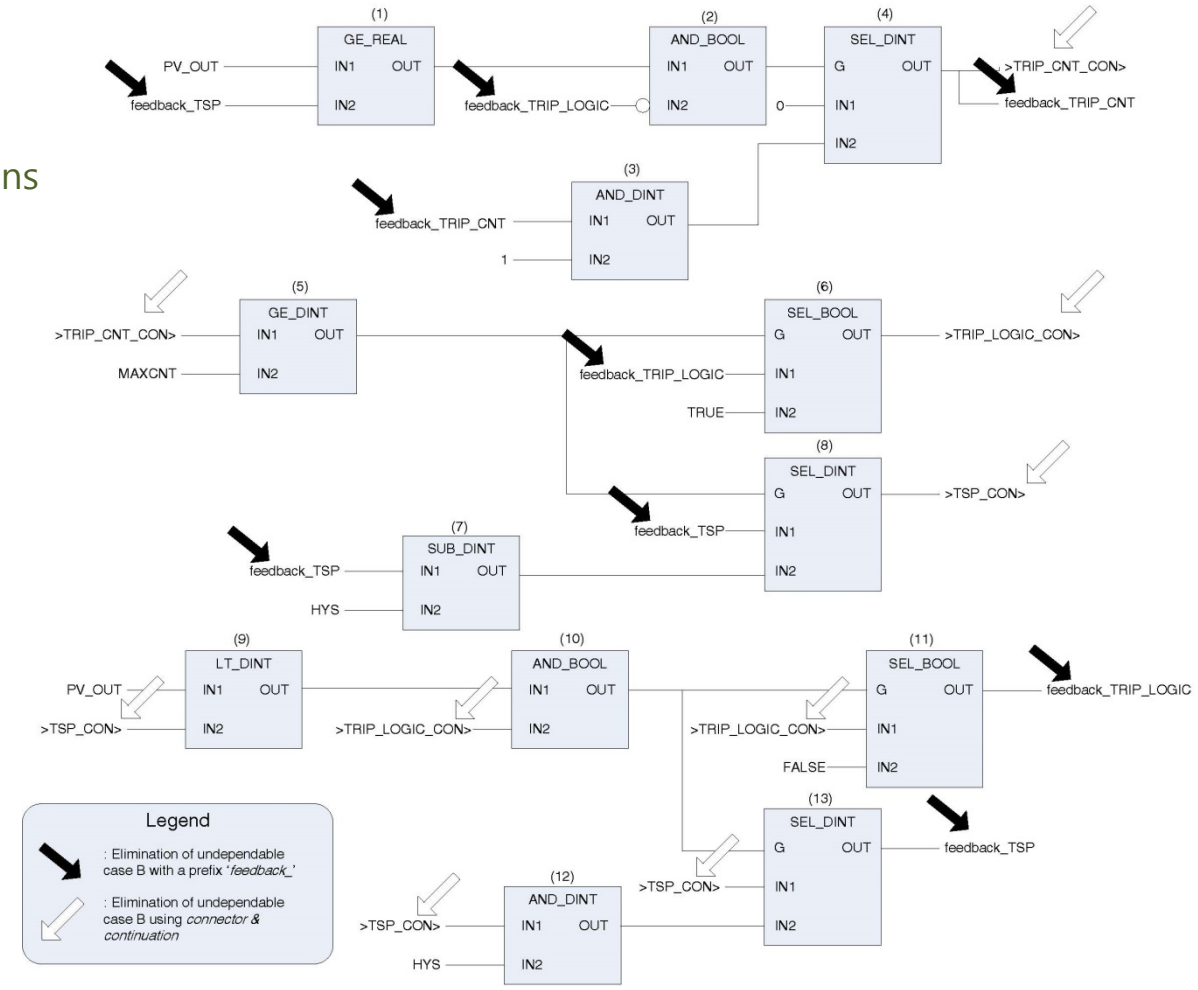
Case study

- FIXED RISING
  - one of logics in RPS
  - the engineering tool: pSET
- Overwriting output ports
- Implicit execution order



Case study

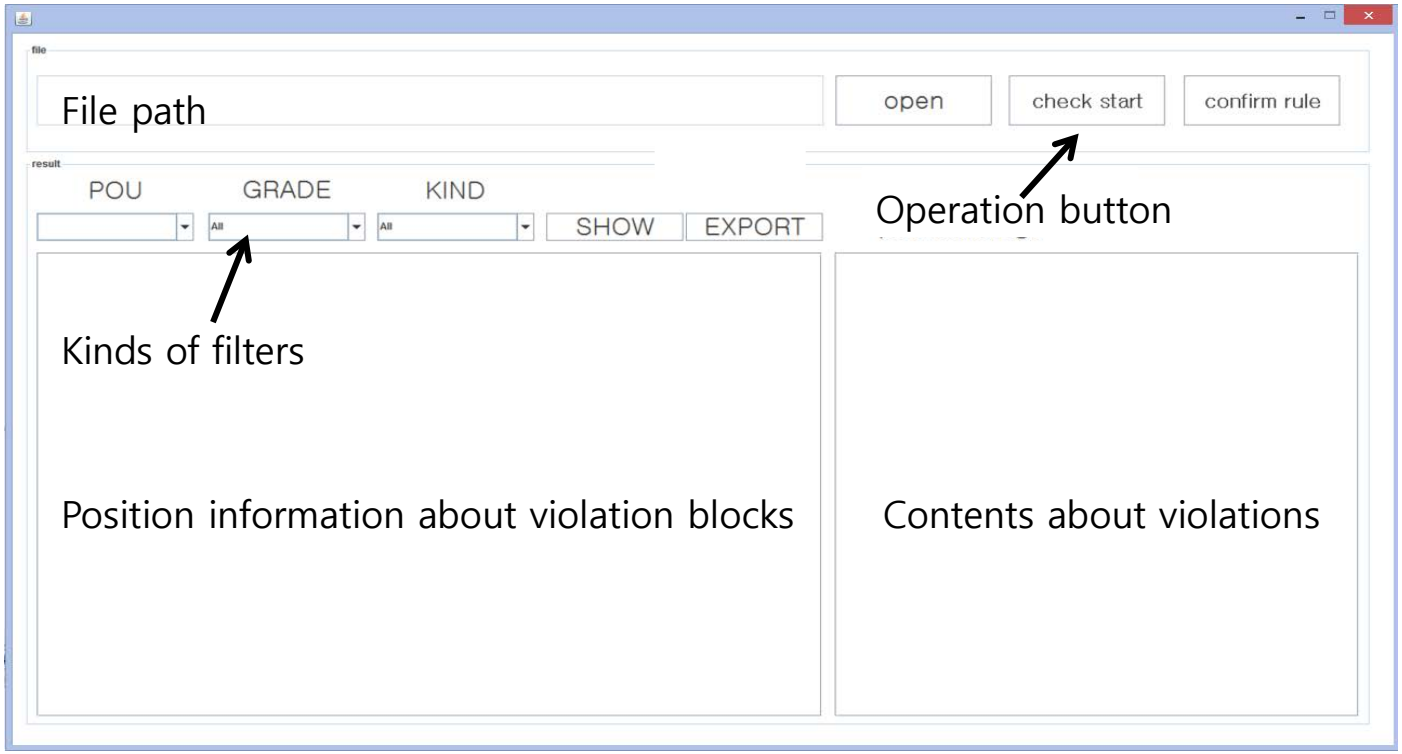
- Eliminate overwriting
  - use connections/continuations
  - use feedback variables
- Clarify explicit execution order



CURRENT STATUS

FBDChecker

- CASE tool : FBDChecker
  - Automation tool for checking FBD programs about guidelines
  - the *de facto* standard format of FBD files (PLCopen TC6)
  - checks FBD programs

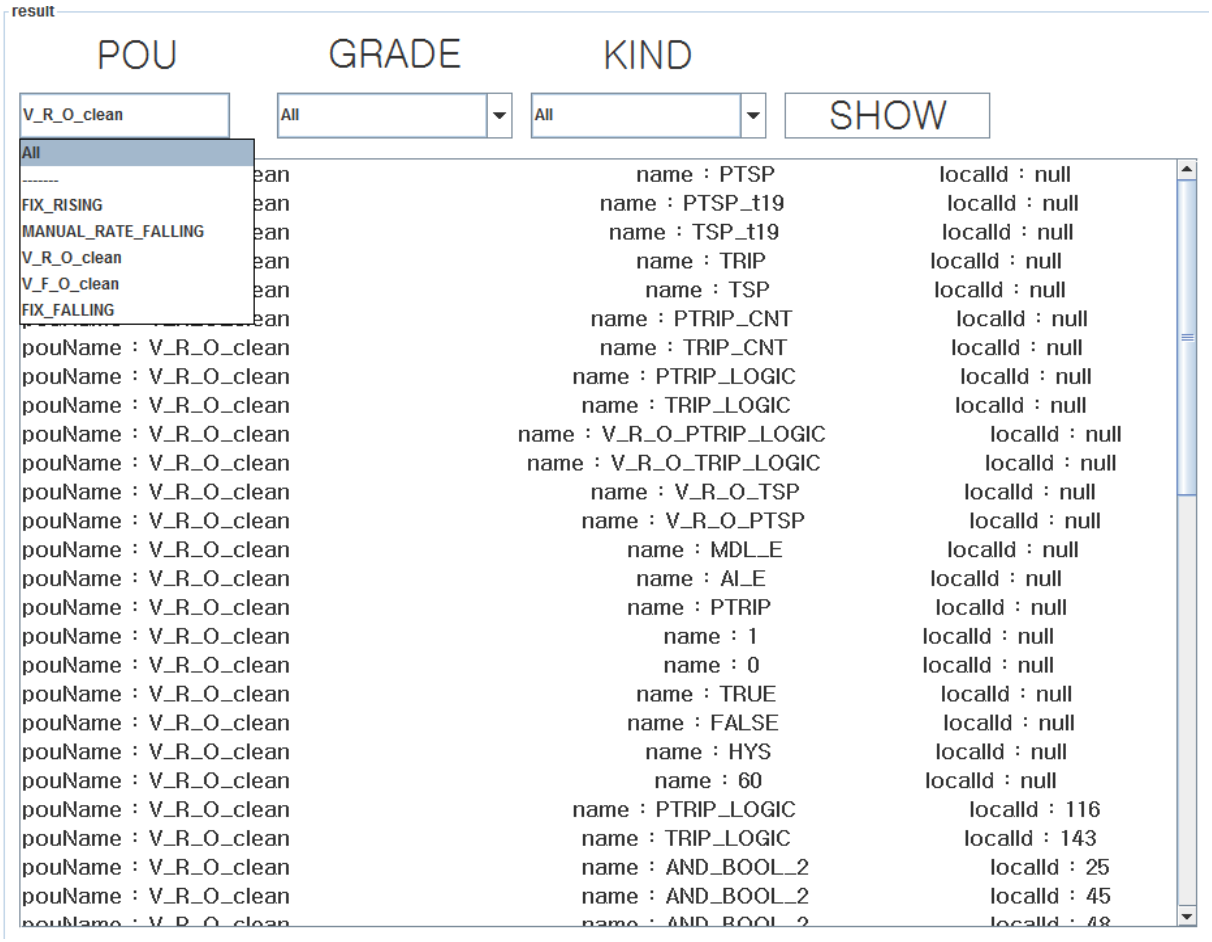


FBDChecker - Guidelines

- Reliability
  - Execution order
  - Eliminating incorrect move block
  - Implicit/explicit type conversion
  - Variable initialization
  - Etc.
- Maintainability
  - Naming convention
    - Length – too short, too long
  - Eliminating crossed connections
  - Eliminating overlapped blocks
  - Etc.

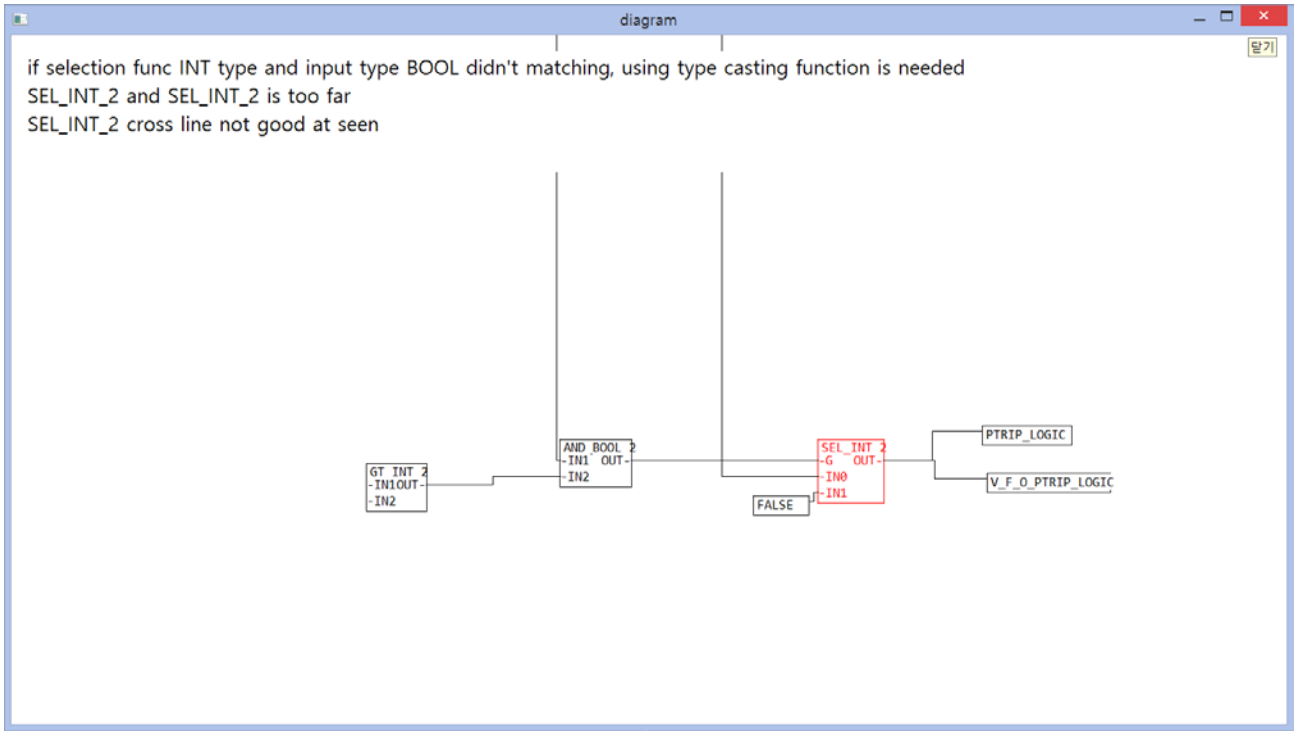
FBDChecker - Results

- Filtering by POU, types of guideline



FBDChecker - Results

- An example of a part of diagram in a logic
  - Too far block
  - Crossed line
  - Type conversion

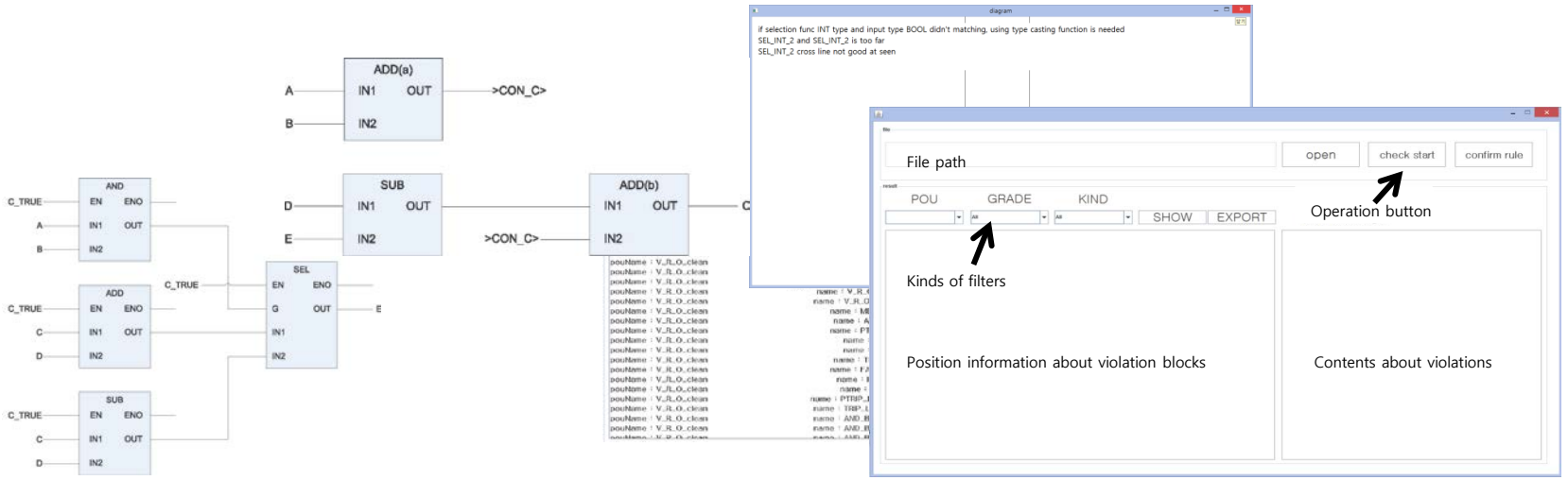


CONCLUSION

Conclusion

- FBD programming guidelines
  - 5 specific cases
  - more guidelines in current status
  - an automatic guideline checker (FBDChecker)

- Future work
  - improving quality and quantity of guidelines



THANK YOU

Q & A

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