Whimori

산업제어용 프로그래밍환경과 검증시스템

신승철
한국기술교육대

2009. 7. 9

소프트웨어 무결점 연구센터 웍샵

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Background

- PLC(Programmable Logic Controller)
  - a special-purpose microcontroller
  - industrial automation for facilities, equipments, devices
- Development Environments
  - for PLC control programs
  - IsaGraf, Veremiz
  - graphic editors, simulator, target code generators
- IEC61131: PLC standard
  - PLC architecture
  - control programming languages

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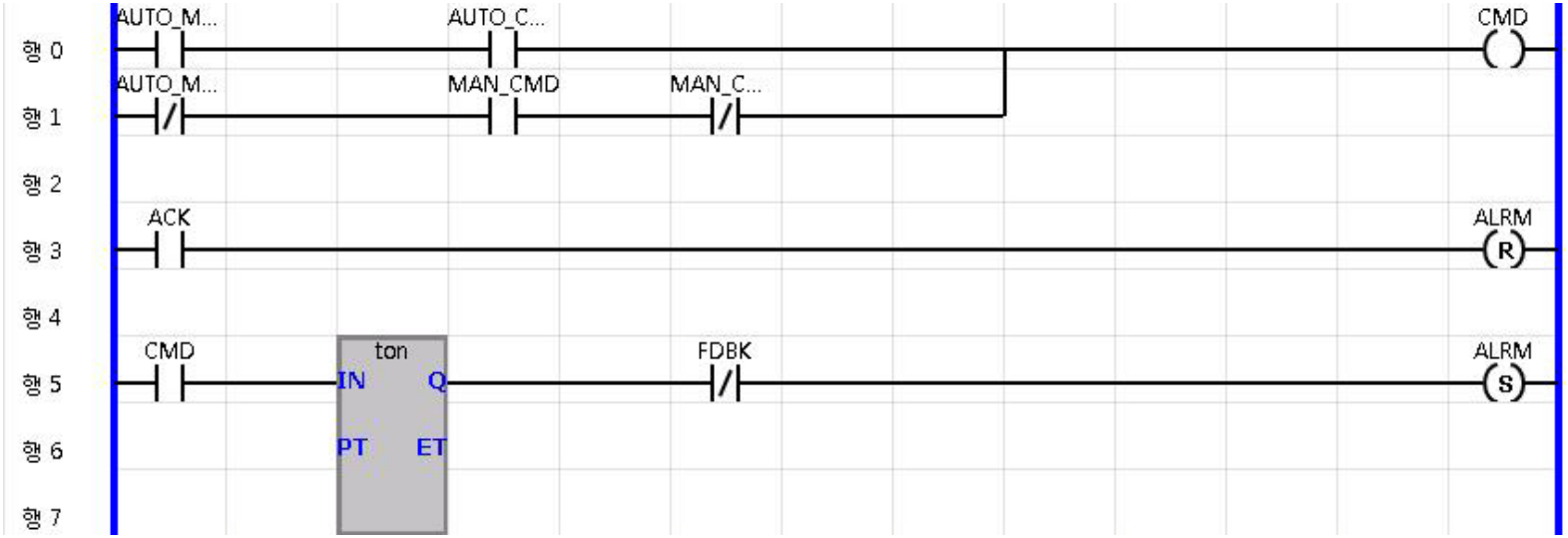
PLs for PLC are Street Fighters

- evolved from historical needs
- not driven by modern theory
- no latest abstraction
  - object orientation
  - abstract data types
  - graphical programming environments
- error prone and lower abstract

IEC61131-3: Ladder Diagram



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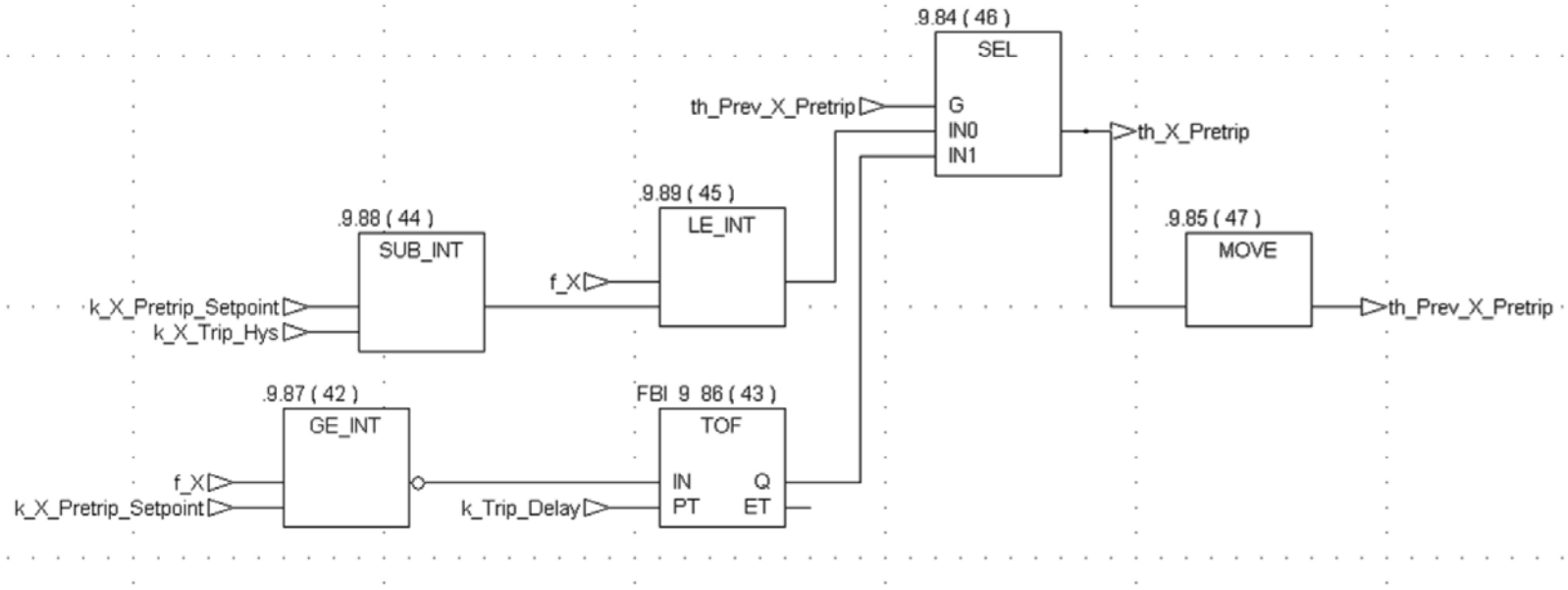
IEC61131-3: Structured Text

```
IF R1 THEN
   OFLO := 0; EMPTY := 1; PTR := -1;
   NI := LIMIT (MN:=1,IN:=N,MX:=128); OUT := 0;
ELSIF POP & NOT EMPTY THEN
   OFLO := 0; PTR := PTR-1; EMPTY := PTR < 0;
   IF EMPTY THEN OUT := 0;
   ELSE OUT := STK[PTR];
   END_IF ;
ELSIF PUSH & NOT OFLO THEN
   EMPTY := 0; PTR := PTR+1; OFLO := (PTR = NI);
   IF NOT OFLO THEN OUT := IN ; STK[PTR] := IN;
   ELSE OUT := 0;
   END_IF ;
END_IF ;
```

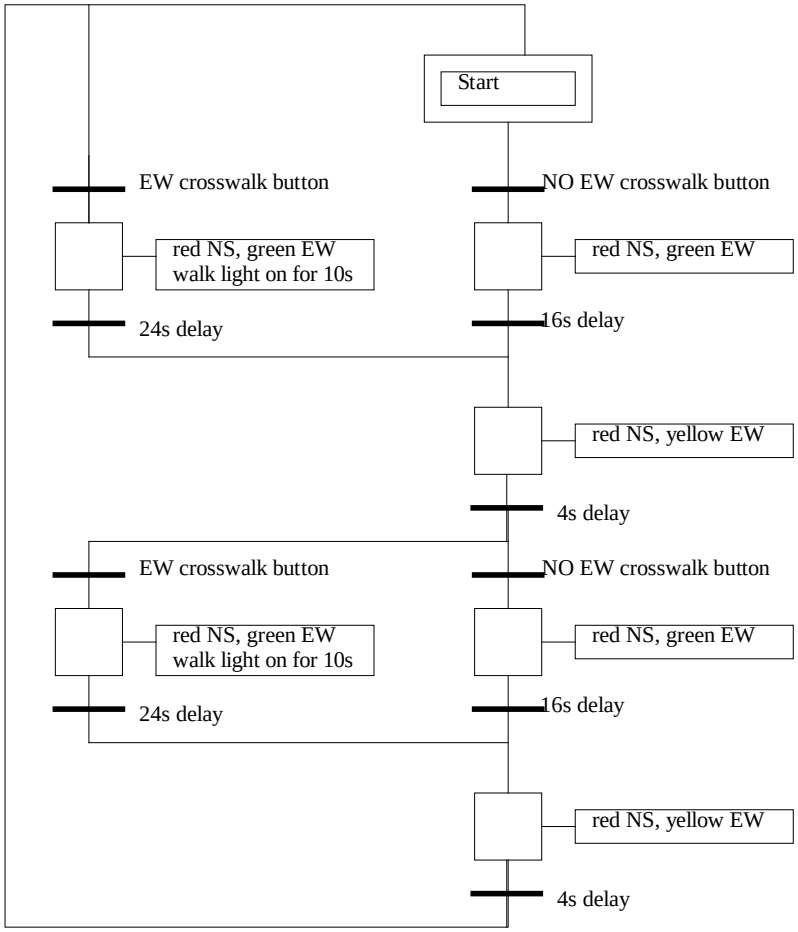
IEC61131-3: Instruction List

```
POP_STK:    LD    0
            ST    OFLO          (* Popped stack is not overflowing *)
            LD    PTR
            SUB   1
            ST    PTR
            LT    0             (* Empty when PTR < 0 *)
            ST    EMPTY
            JMPC  ZRO_OUT
            LD    STK[PTR]
            JMP   SET_OUT
PUSH_STK:   LD    0
            ST    EMPTY         (* Pushed stack is not empty *)
            LD    PTR
            ADD   1
            ST    PTR
            EQ    NI            (* Overflow when PTR = NI *)
            ST    OFLO
            JMPC  ZRO_OUT
            LD    IN
            ST    STK[PTR]      (* Push IN onto STK *)
            JMP   SET_OUT
ZRO_OUT:    LD    0             (* OUT=0 for EMPTY or OFLO *)
SET_OUT:    ST    OUT
```

IEC61131-3: Function Block Diagram



IEC61131-3: Sequential Function Chart



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How to make Street Fighters gentle

- New PLs and environments
  - abstract, problem-oriented development
  - simple and rigorous for safe programming
- Existing PLs + analysis and verification
  - clear understanding of semantics
  - tools for analysis

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Motivation

- A new development environment
  - based on IEC61131-3 standards
  - language processors based on formal semantics
  - supporting verification based on formal methods
  - supporting open data format
  - implemented on an open framework
- A testbed for verification of control programs
  - formally specified syntax and semantics
  - formally designed language processors

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- IEC 61131-3 language standards
- Formal Semantics based
- Language Translators formally designed
- Virtual Machine formally designed
- TC6 XML Scheme as an open data format
- Eclipse platform as an open framework

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PLC program verification

- which source language?
- having environment or not?
- scan cycle implicit or explicit?
- having timer or not?
- which model?
  - automata, transition systems, Petri net
  - logics, languages, calculi
  - constraints
- which verification engine?

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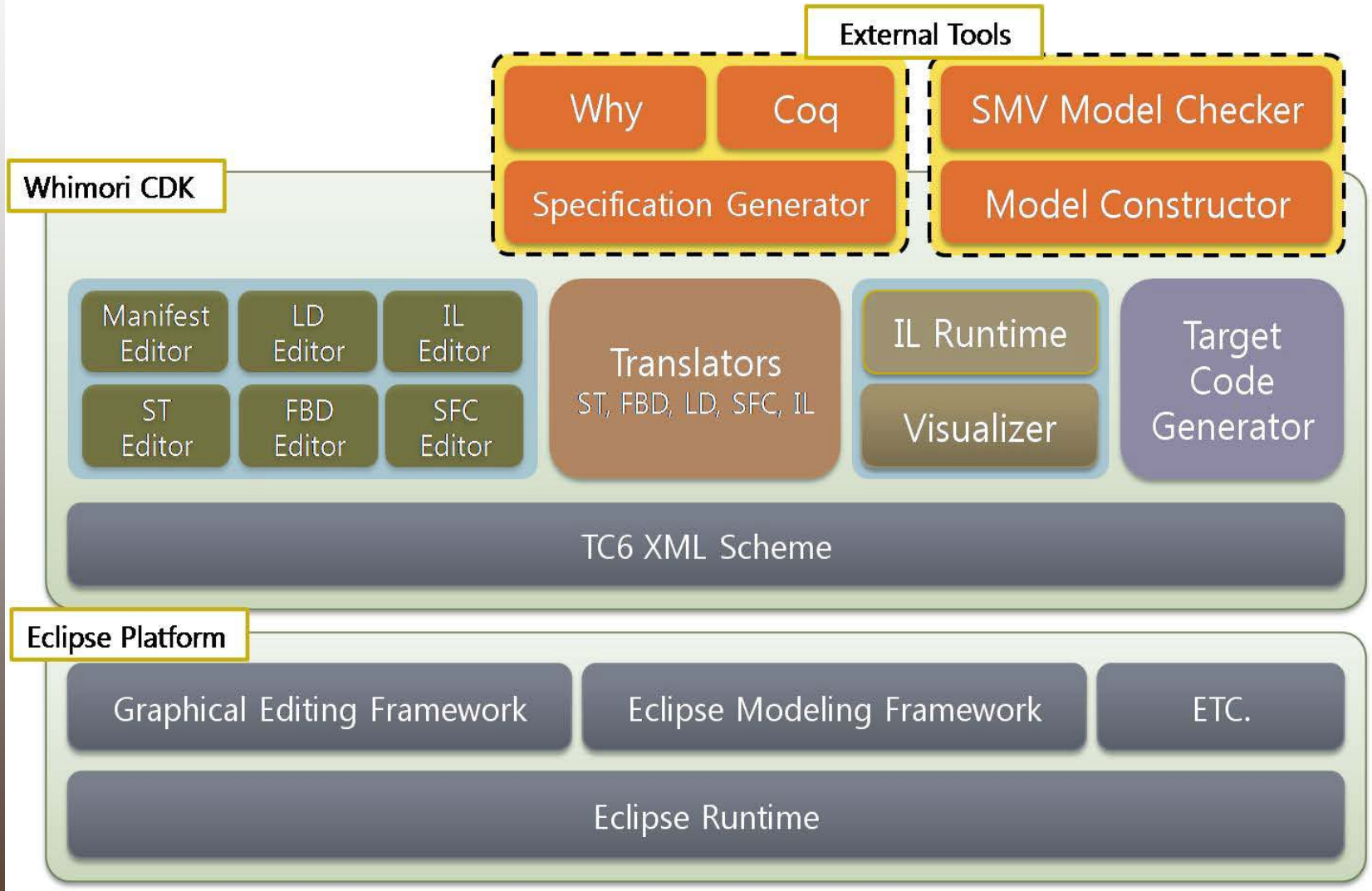
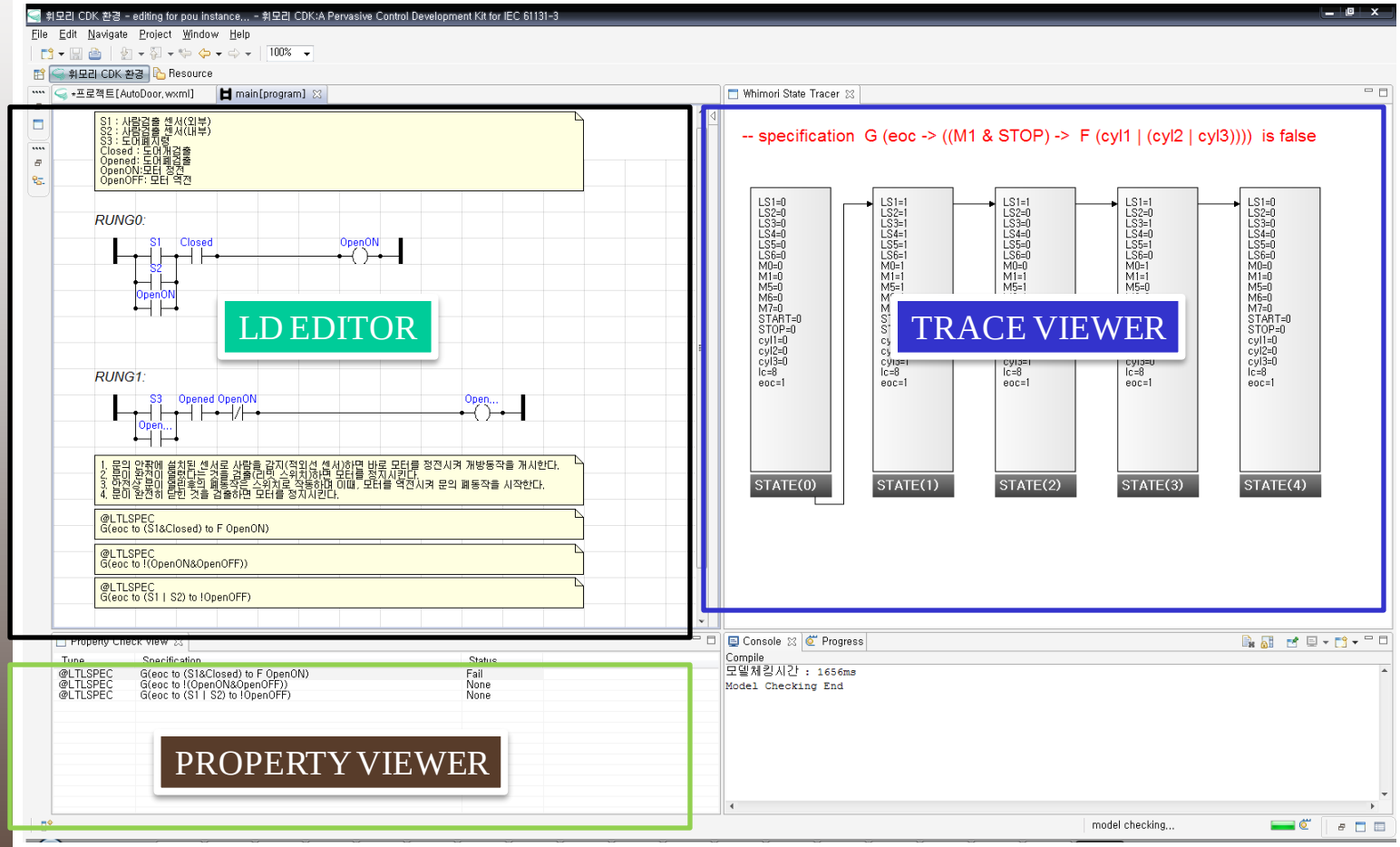
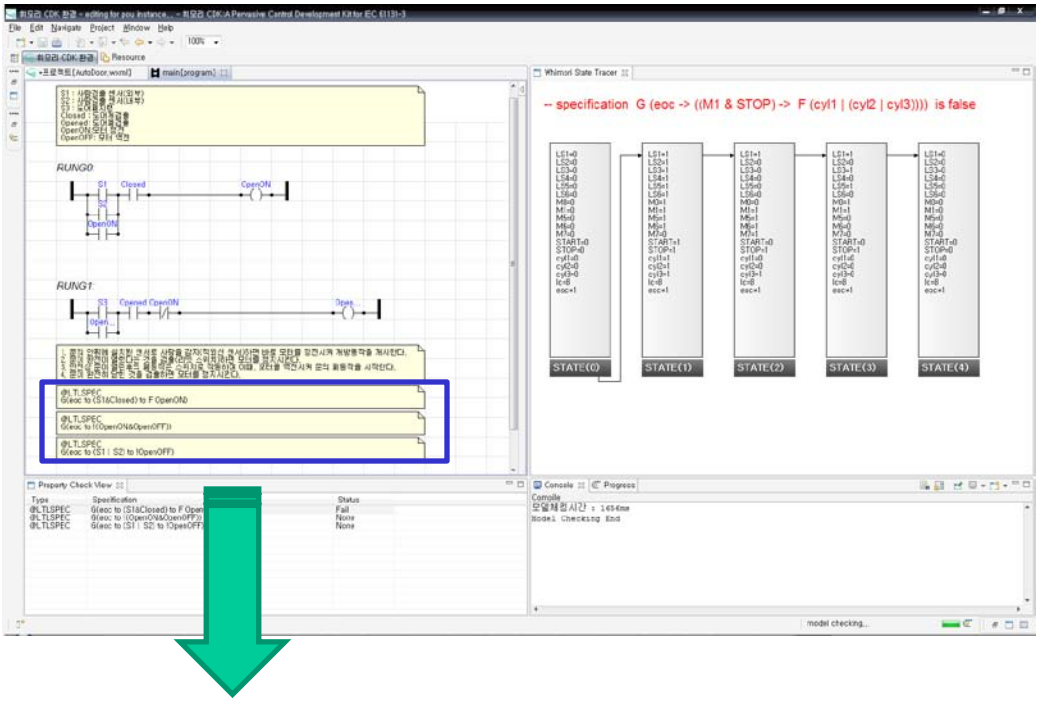
Whimori architecture



Whimori + SMV model checker



LTL Specification

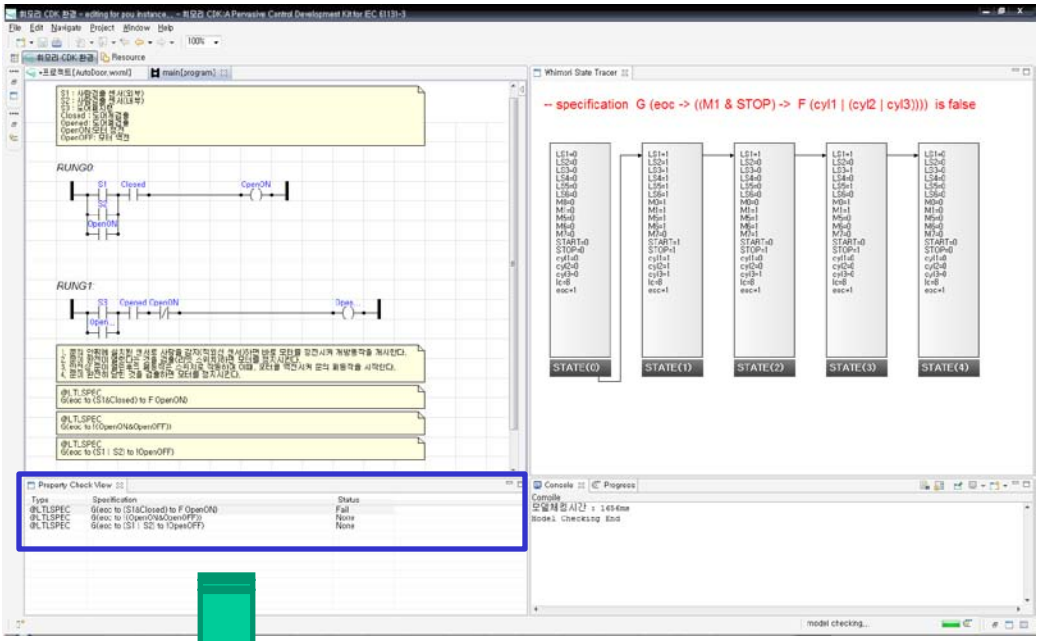



```
@LTLSPEC
G(eoc to (S1&Closed) to F OpenON)
```

```
@LTLSPEC
G(eoc to !(OpenON&OpenOFF))
```

```
@LTLSPEC
G(eoc to (S1 | S2) to !OpenOFF)
```

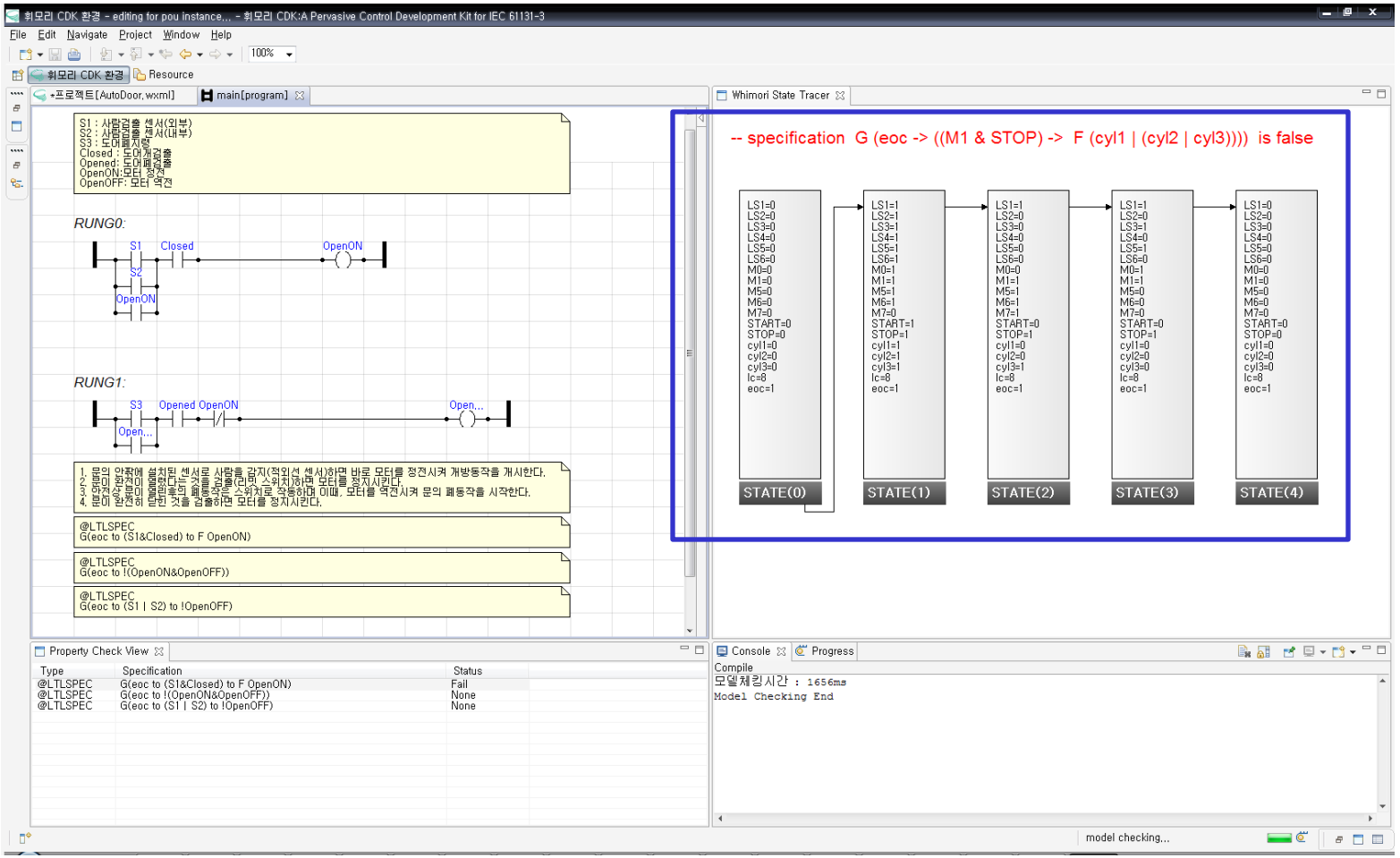
Model Checking Results



Property Check View

Type	Specification	Status
@LTLSPEC	G(eoc to (S1&Closed) to F OpenON)	Fail
@LTLSPEC	G(eoc to !(OpenON&OpenOFF))	None
@LTLSPEC	G(eoc to (S1 | S2) to !OpenOFF)	None

Counter Examples



Deductive Verification using Why

- Software Verification Platform
- verification condition generator(VCG)
- Back-end for verification of C/Java programs
- Why code = ML like program + annotations

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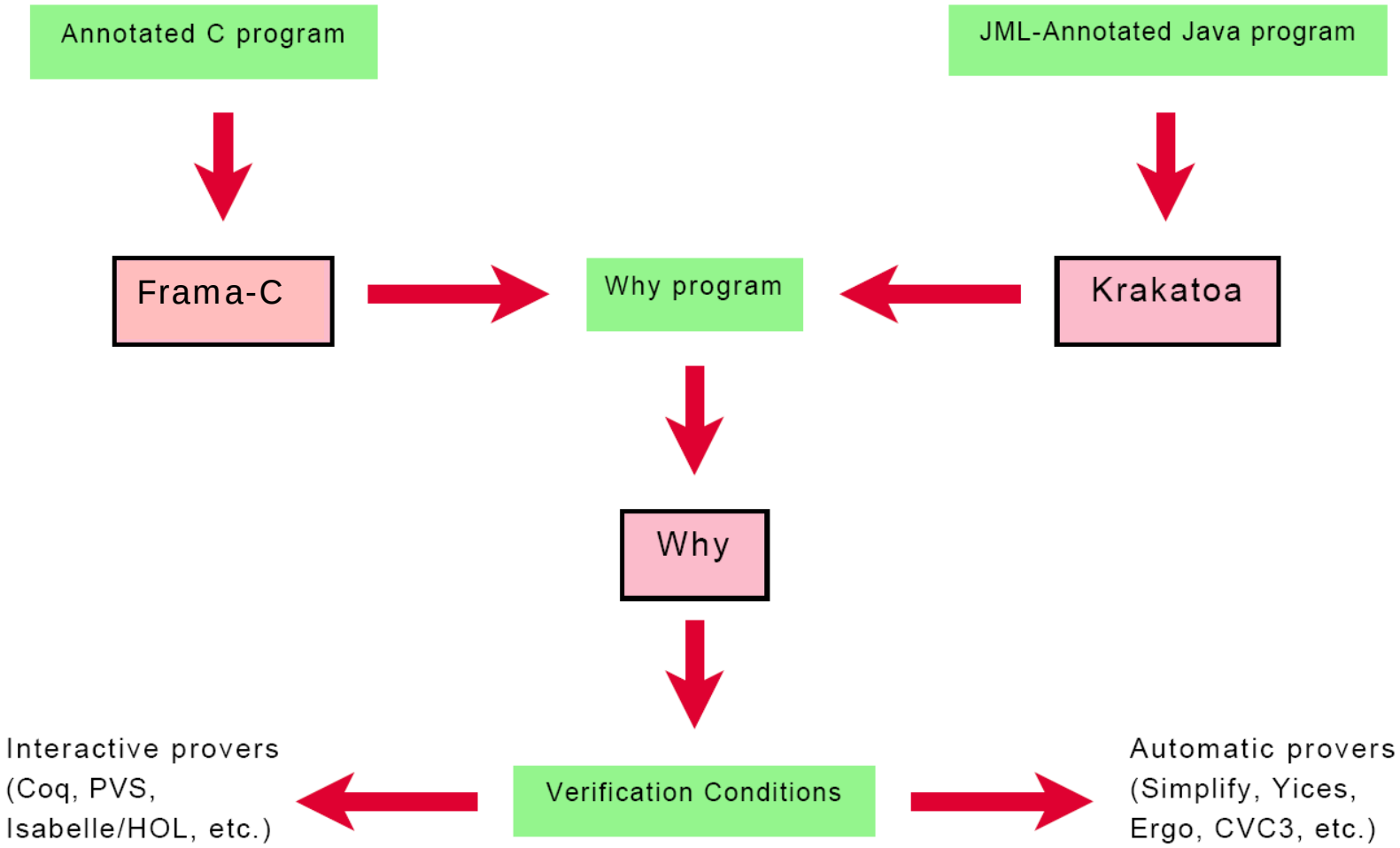
Why?


Annotated C program
JML-Annotated Java program
Frama-C
Why program
Krakatoa
Why
Interactive provers
(Coq, PVS,
Isabelle/HOL, etc.)
Verification Conditions
Automatic provers
(Simplify, Yices,
Ergo, CVC3, etc.)

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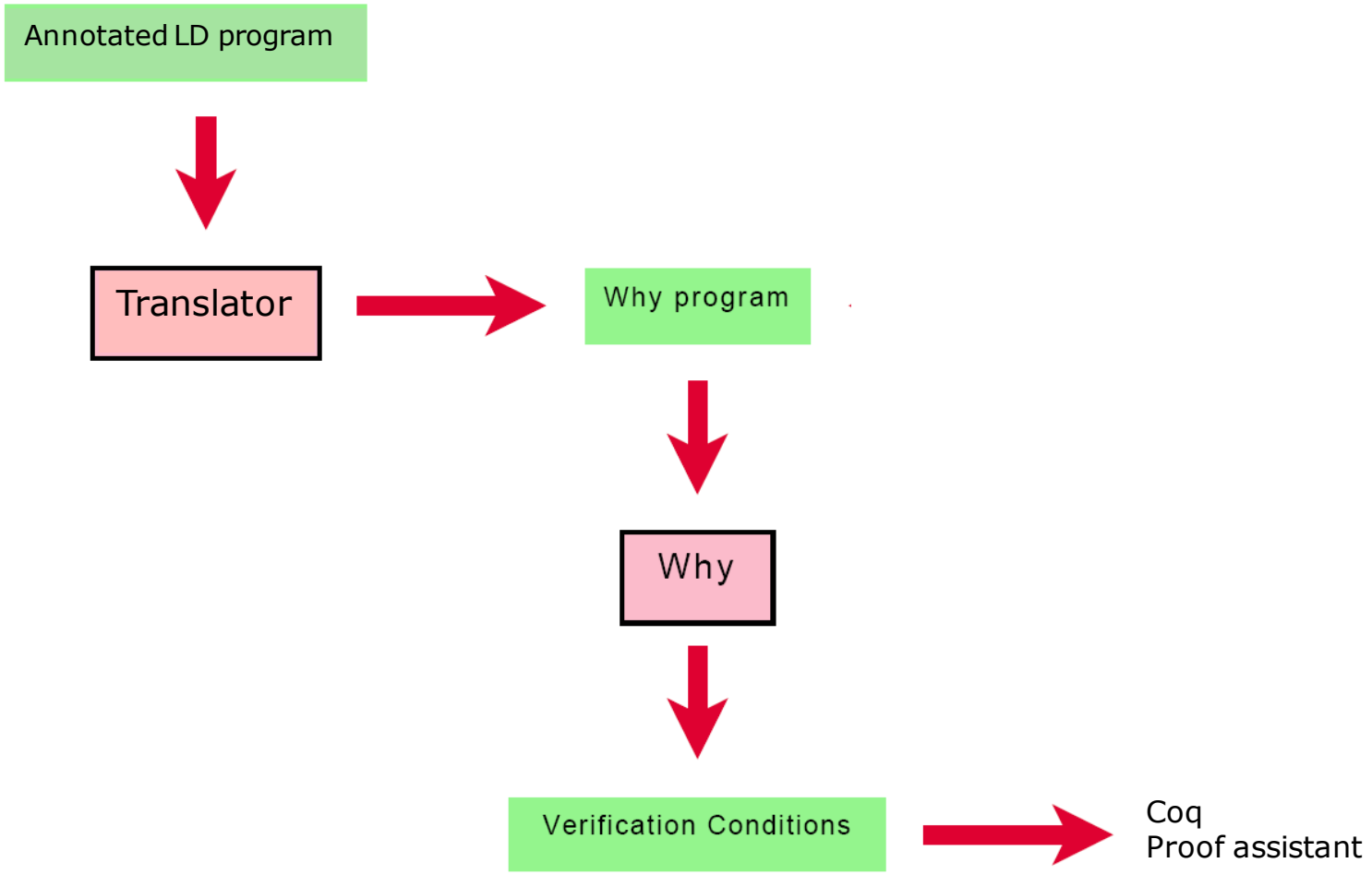
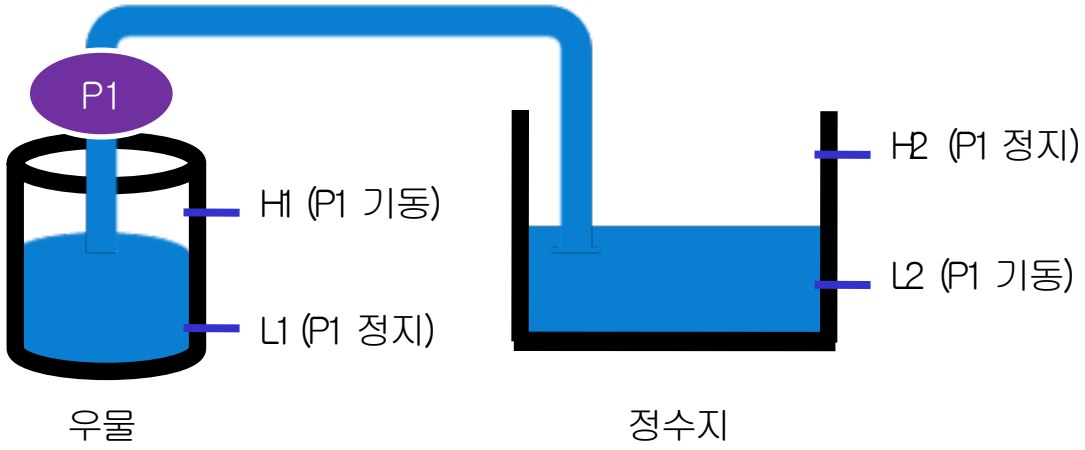
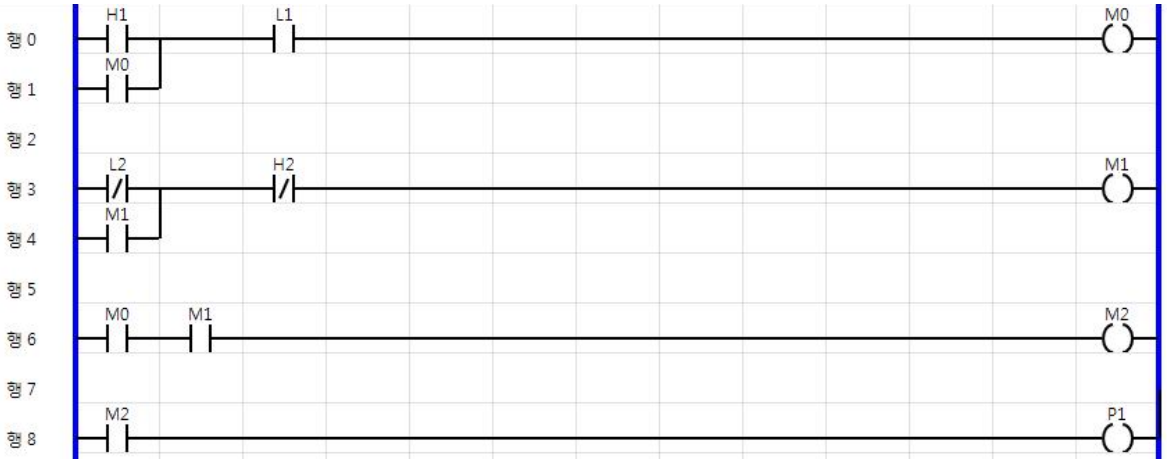
Deductive Verification of Ladder Diagram



Very simple example





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Annotated Specification

```
/*@ ensures
    @ ( ( !L1 ||  H2)  => !P1 )  &&
    @ ( (\old(M0)  && \old(M1) && \old(M2) && \old(P1)  ) =>
    @   (!H1 && L1 && !H2 ) =>
    @   P1  )
    @*/
```

우물의 수위가 낮거나(L1 이하)
정수지의 수위가 높을 때(H2 이상)
과연 펌프는 동작하지 않는가?
&&
펌프가 동작하는 상태에서
우물의 수위가 중간(H1과 L2 사이)이고
정수지의 수위는 높지 않을 때(H2이하)
계속 펌프는 동작하는가?

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Why code

```
(*
 * l1, l2, h1, h2 : inputs
 * p1 : output
 *)
(* global variables *)
parameter p1 : int ref
(* the pump *)
parameter m0 : int ref
parameter m1 : int ref
parameter m2 : int ref
```

```
(* body *)
let water_impl =
 fun (l1 : int) (l2 : int) (h1 : int) (h2 : int)  ->
  {  }
  (
  begin
    (m0 :=  (if  ( (((neq_int_ h1) (0)) || ((neq_int_ !m0) (0)))
                          && ((neq_int_ l1) (0)) )
                then (1)
                else (0)));
   (m1 :=  (if ( (((eq_int_ l2) (0)) || ((neq_int_ !m1) (0)))
                          && ((eq_int_ h2) (0)) )
                then (1)
                else (0)));
   (m2 :=  (if  (((neq_int_ !m0) (0)) &&  ((neq_int_ !m1) (0)))
                then (1)
                else (0)));
   (p1 := !m2)
 end)
  { ( (eq_int(l1, (0)) or neq_int(h2, (0))) ->  not (neq_int(p1,
(0))))
   and ( ( neq_int(m0@, (0)) and neq_int(m1@, (0))  and
           neq_int(m2@, (0)) and neq_int(p1@, (0)) )   ->
         ( eq_int(h1, (0)) and neq_int(l1, (0)) and eq_int(h2,
(0)) )  ->
           (neq_int(p1, (0))) ) }
```

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Why(VCG)

- Generate Verification Conditions
- weakest preconditions calculus

$$wp(\{p'\}\ e\ \{q'\},q) = p' \wedge \forall result.\forall \omega.q' => q$$

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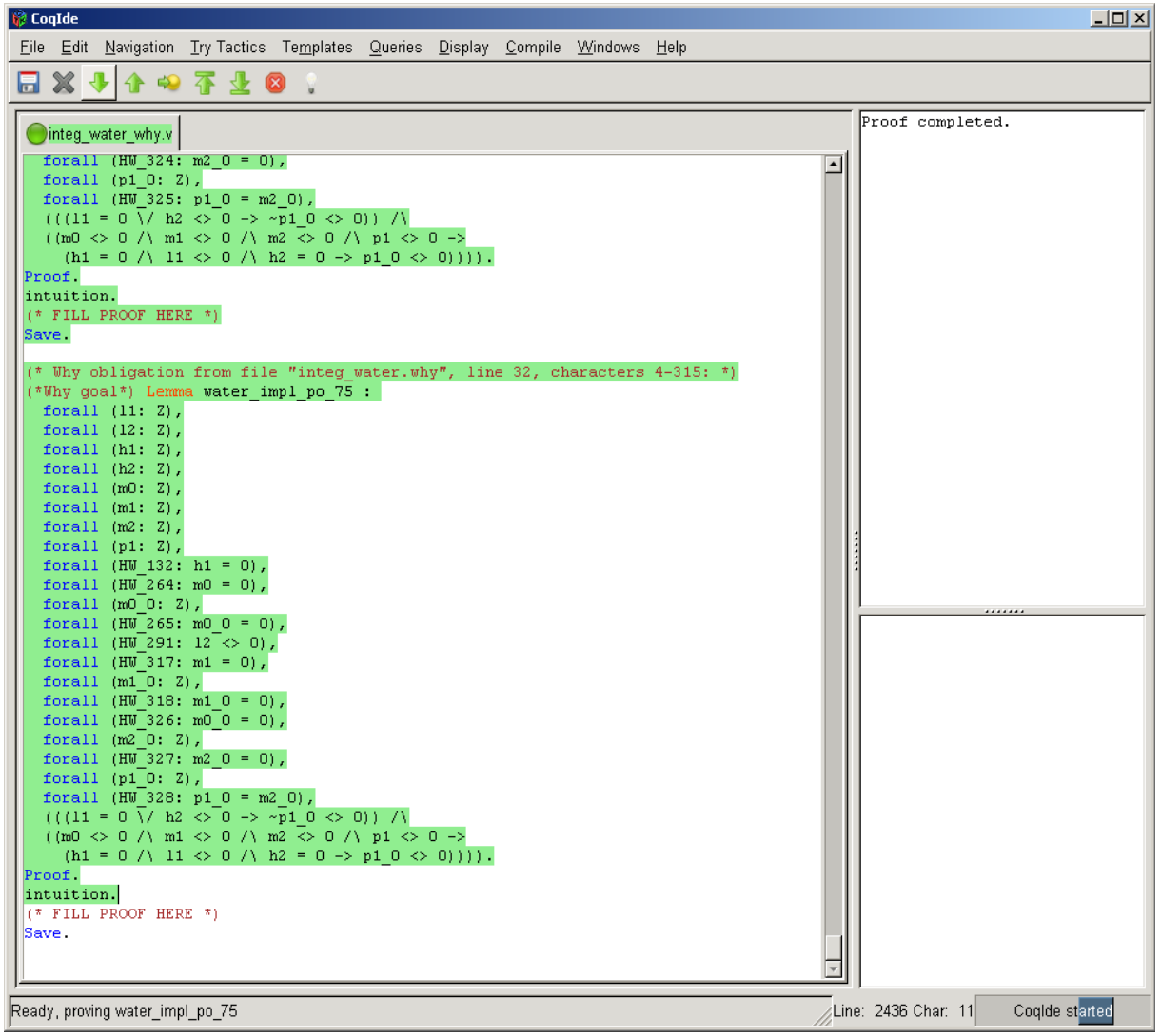
Proving Verification Conditions by Coq




```
  forall (HW_324: m2_0 = 0),
  forall (p1_0: Z),
  forall (HW_325: p1_0 = m2_0),
  (((l1 = 0 \/ h2 <> 0 -> ~p1_0 <> 0)) /\
  ((m0 <> 0 /\ m1 <> 0 /\ m2 <> 0 /\ p1 <> 0 ->
    (h1 = 0 /\ l1 <> 0 /\ h2 = 0 -> p1_0 <> 0)))).
Proof.
intuition.
(* FILL PROOF HERE *)
Save.

(* Why obligation from file "integ_water.why", line 32, characters 4-315: *)
(*Why goal*) Lemma water_impl_po_75 :
  forall (l1: Z),
  forall (l2: Z),
  forall (h1: Z),
  forall (h2: Z),
  forall (m0: Z),
  forall (m1: Z),
  forall (m2: Z),
  forall (p1: Z),
  forall (HW_132: h1 = 0),
  forall (HW_264: m0 = 0),
  forall (m0_0: Z),
  forall (HW_265: m0_0 = 0),
  forall (HW_291: l2 <> 0),
  forall (HW_317: m1 = 0),
  forall (m1_0: Z),
  forall (HW_318: m1_0 = 0),
  forall (HW_326: m0_0 = 0),
  forall (m2_0: Z),
  forall (HW_327: m2_0 = 0),
  forall (p1_0: Z),
  forall (HW_328: p1_0 = m2_0),
  (((l1 = 0 \/ h2 <> 0 -> ~p1_0 <> 0)) /\
  ((m0 <> 0 /\ m1 <> 0 /\ m2 <> 0 /\ p1 <> 0 ->
    (h1 = 0 /\ l1 <> 0 /\ h2 = 0 -> p1_0 <> 0)))).
Proof.
intuition.
(* FILL PROOF HERE *)
Save.
```

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Summary

- Whimori CDK: IDE for PLC programmng
- based on Modern PL theory
- Verification tools featured
  - Model checking
  - Theorem proving