White-box Testing by Combining Deduction-based Specification Extraction and Black-box Testing

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www.key-project.org

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Two Kinds of Specifications

Requirement Specificaiton

- Given by the user
- Role: To be tested or verified

Full Specifictaion

- Must comply with the IUT (Impl. Under Test)
- Reflects the structure of the program
- Can be extracted automatically

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Tool Chain

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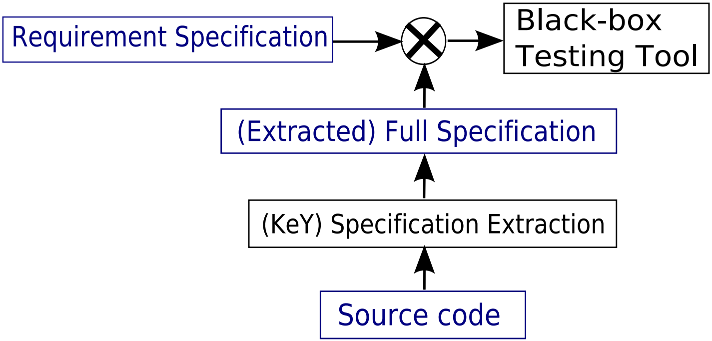
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Black-box Testing Tool
(Extracted) Full Specification
(KeY) Specification Extraction
Source code

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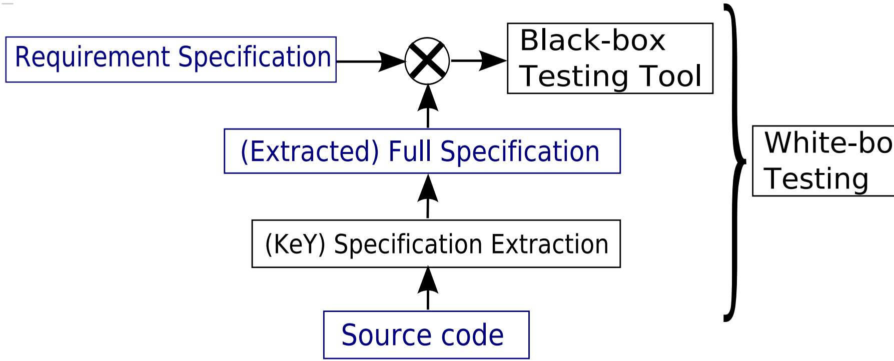
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Benefits

- Using of existing Black-box Testing Tools for White-box testing
- Separation of concerns - Modularity
- Combination of Coverage Criteria

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The KeYSystem

Program Variable = non-rigid Function Symbol

$$(\textit{prog.var.})\ \texttt{a} \quad = \quad a\ \text{(logic const.)}$$
$$\texttt{o.a} \quad = \quad a(o)$$

Modal Operators

$$[p]\phi \qquad \langle p\rangle\phi \qquad \{a := b\}\phi$$
$$\langle \texttt{o.a = t;u.b = s}\rangle\phi \quad \rightsquigarrow \quad \{a(o) := t \,||\, b(u') := s'\}\phi$$
$$\{\textit{for}\ x; f_x := g_x\}\phi \quad \rightsquigarrow \quad \{f_n := g_n||..||f_0 := g_0\}\phi$$

Sequent Calculus Rules

$$\frac{\Gamma, c = \textit{true} \Longrightarrow \langle \texttt{p}\rangle\phi, \Delta \qquad \Gamma, c = \textit{false} \Longrightarrow \langle \texttt{q}\rangle\phi, \Delta}{\Gamma \Longrightarrow \langle \texttt{if(c)\{p\}else\{q\}..}\rangle\phi, \Delta}$$

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Example IUT

```
public class AbsDiff{
    public static int d;
     /*@ public normal_behavior
       @  requires true;
       @  ensures d==x-y || d==y-x;
       @  ensures d>=x-y && d>=y-x;
       @*/
     public static void diff(int x, int y){
         if(x<y) d=y;
          else   d=x;
         if(d<=y)d=d-x;
          else   d=d-y;
     }
}
```

Specification Extraction (Structural properties)

$$\dfrac{\dfrac{\dfrac{\texttt{x} < \texttt{y}, \texttt{x} \leq \texttt{y} \Longrightarrow \{\texttt{d} := \texttt{y-x}\}\Delta \qquad \dfrac{*}{\texttt{x} < \texttt{y}, \texttt{x} > \texttt{y} \Longrightarrow \{\texttt{d} := \texttt{y-x}\}\Delta}}{\ldots}}{\texttt{x} < \texttt{y} \Longrightarrow \{\texttt{d} := \texttt{y}\}[\texttt{if} \ \ldots]\Delta} \qquad \dfrac{(B_3) \qquad (B_4)}{\texttt{x} \geq \texttt{y} \Longrightarrow \{\texttt{d} := \texttt{x}\}[\texttt{if} \ \ldots]\Delta}}{\Longrightarrow [\texttt{if(x<y)d=y;else d=x; if(d<=y)}\ldots]\Delta}$$

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```
B1: req x<y && y<=y ens d=\old(y-x); also
B3: req x>=y && x<=y ens d=\old(x-y); also
B4: req x>=y && x>y ens d=\old(x-y);
```

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  @  requires true;
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  @  ensures d>=x-y && d>=y-x;
  @ also
  @  requires y < x;
  @  ensures d == \old(x - y);
  @ also
  @  requires y == x;
  @  ensures d == \old(0);
  @ also
  @  requires y > x;
  @  ensures d == \old(y - x);
  @*/
```

Example IUT

```
/*@ public normal_behavior
  @  requires y < x && true;
  @  ensures d == \old(x - y)
  @   && (d==x-y || d==y-x) && d>=x-y && d>=y-x;
  @ also
  @  requires y == x && true;
  @  ensures d == \old(0)
  @   && (d==x-y || d==y-x) && d>=x-y && d>=y-x;
  @ also
  @  requires y > x && true;
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  @   && (d==x-y || d==y-x) && d>=x-y && d>=y-x;
  @*/
```

Using the extracted Post Condition

- Requirement Specification

```
requires true;
ensures  (d==x-y || d==y-x) && d>=x-y && d>=y-x
         && d!=MAX_INT;
```

- With Full Specification

```
requires true && y < x;
ensures  (d==x-y || d==y-x) && d>=x-y && d>=y-x
         && d!=MAX_INT &&  d == \old(x - y);
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         && d!=MAX_INT &&  d == \old(x - y);
also
    ...
```

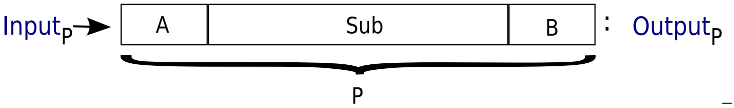
Loops

```
while (k<n) {
  if (j=7) {
    j         = 0;
    line      = new Line(line);
  }
  line.buf[j]=a[k];
  k++; j++;
}
```

Loops (Unfolding)

```
if (k<n)
  {if(j=7){..};if(j>7||k>n)..;
   line.buf[j]=a[k]; k++; j++;
   if(k<n)
     {if(j=7){..};if(j>7||k>n)..;
      line.buf[j]=a[k]; k++; j++;
      ...
     while(k<n){...}
  }
}
```

Contracts Program Replacements



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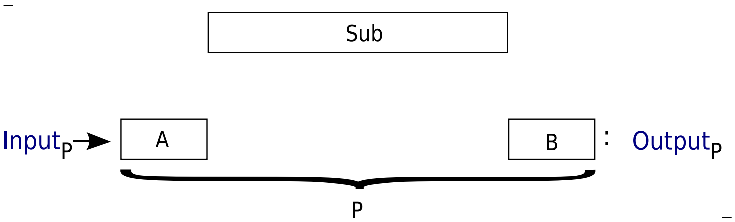

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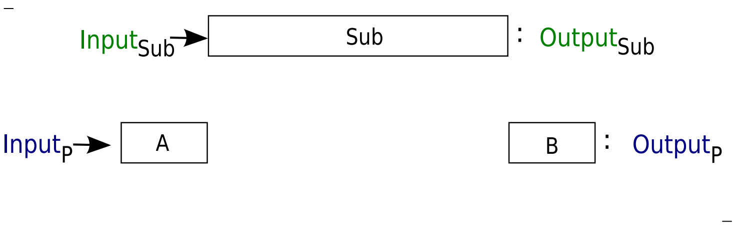

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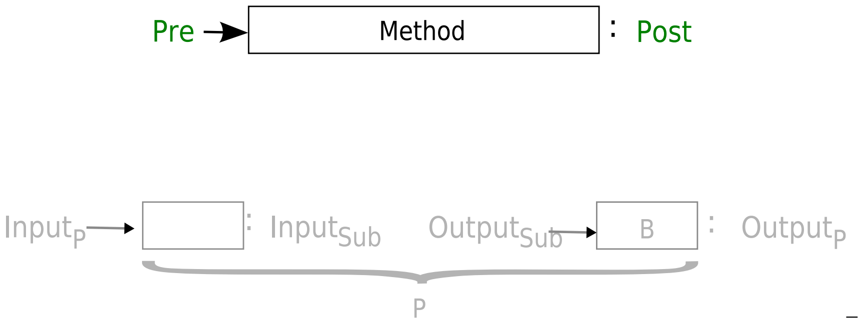

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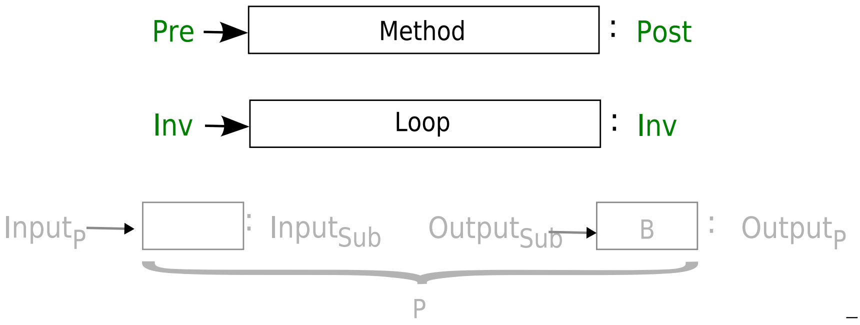

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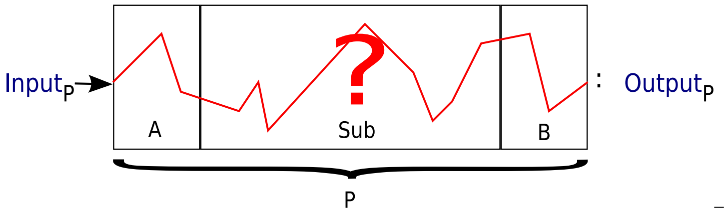

Traditional Contract Rule

$$
\dfrac{\dfrac{Pre \Longrightarrow Pre_C, \langle \mathtt{p} \rangle Post \qquad \dfrac{Post_C \Longrightarrow Post}{\langle \mathtt{p} \rangle Post_C, Pre \Longrightarrow \langle \mathtt{p} \rangle Post}}{Pre_C \rightarrow \langle \mathtt{p} \rangle Post_C, Pre \Longrightarrow \langle \mathtt{p} \rangle Post}}{\underbrace{Pre_C \rightarrow \langle \mathtt{p} \rangle Post_C}_{\textit{Contract}} \Longrightarrow Pre \rightarrow \langle \mathtt{p} \rangle Post}
$$

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$$
\dfrac{\dots \qquad \dfrac{Pre, \{for\ \ x; f(x) := f^{sk}(x)\} Post_C \Longrightarrow \{for\ \ x; f(x) := f^{sk}(x)\} Post}{\langle \mathtt{p} \rangle Post_C, Pre \Longrightarrow \langle \mathtt{p} \rangle Post}}{\dfrac{Pre, Pre_C \rightarrow \langle \mathtt{p} \rangle Post_C \Longrightarrow \langle \mathtt{p} \rangle Post}{\underbrace{Pre_C \rightarrow \langle \mathtt{p} \rangle Post_C}_{Contract} \Longrightarrow Pre \rightarrow \langle \mathtt{p} \rangle Post}}
$$

where $\{forx.f(x) := f^{sk}(x)\}$ abbrev.

$\{for\ \ x_{0,1}.\dots.x_{0,n_0}.f_0(x_{0,1},\dots,x_{0,n_0}) := f_0^{sk}(x_{0,1},\dots,x_{0,n_0})\}$

$\vdots$

$\{for\ \ x_{m,1}.\dots.x_{m,n_m}.f_m(x_{m,1},\dots,x_{m,n_m}) := f_m^{sk}(x_{m,1},\dots,x_{m,n_m})\}$

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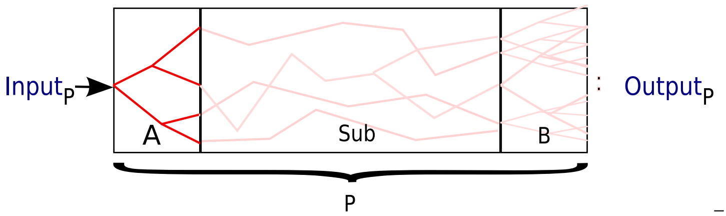
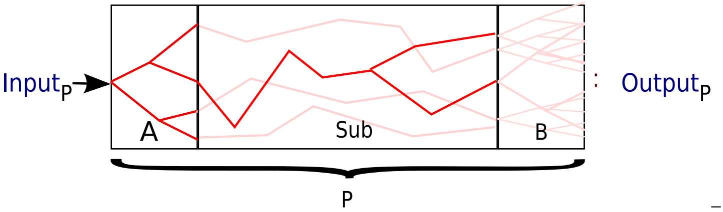
Explicit Structural Coverage



$$Pre, \{for\ x; f(x) := f^{sk}(x)\} Post_C$$
$$\implies \{for\ x; f(x) := f^{sk}(x)\} Post$$

Explicit Structural Coverage



$$Pre, \{for\ \ x; f(x) := f^{sk}(x)\} Post_C$$
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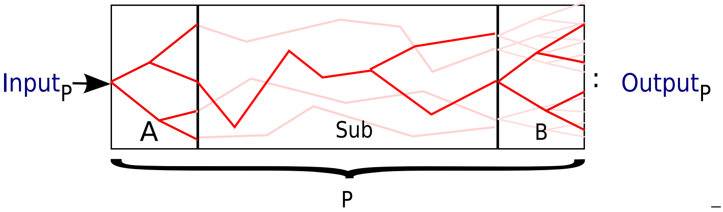

$$Pre, \{for\ \ x; f(x) := f^{sk}(x)\} Post_C$$
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Loops (Invariants)

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  if (j=7) {
    j        = 0;
    line     = new Line(line);
  }
  line.buf[j]=a[k];
  k++; j++;
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Invariant:

$$0 \leq k \leq n \wedge 0 \leq j \leq n \wedge j \leq 7$$

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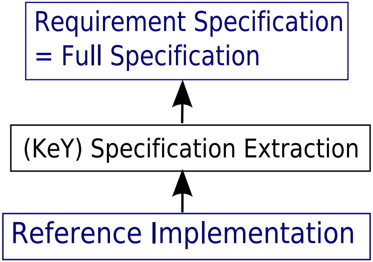
Requirement Specification from a Reference Implementation



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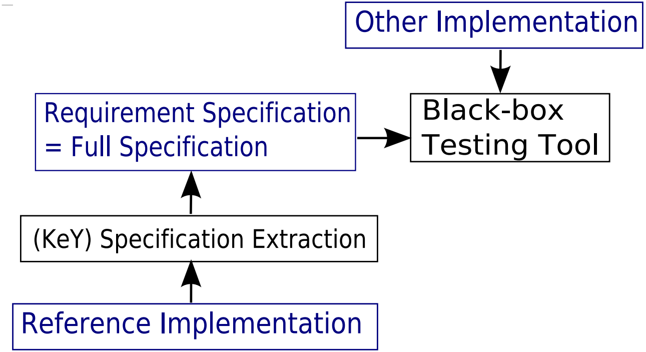

Conclusion

- Enrich existing Requirement Specification with Program Structure
- Use Black-box Testing tool for White-box testing
- Tools that use Symbolic Execution can be extended
- An Importer and Exporter for a Specification language has to be implemented

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White-box Testing by Combining Deduction-based Specification Extraction and Black-box Testing