Representative Litmus Tests

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About this document: Representative Litmus Tests

This document contains examples, illustrations of forbidden executions, and links to web interfaces of the herd simulator of the HSA model.

Audience

This document is written for system and component architects interested in supporting the HSA infrastructure (hardware and software) within platform designs.

HSA Information Sources

1. Sequentially-consistent synchronizing operations

LISA HSA01

----- Start y=0; x=0;
----- P0
w[atomic, screl, wg] x 1
----- P1
w[atomic, screl, wg] y 1
----- P2
r[atomic, scacq, wg] r0 x r[atomic, scacq, wg] r1 y
----- P3
r[atomic, scacq, wg] r0 y r[atomic, scacq, wg] r1 x

----- Scope
scopes: (wg 0 1 2 3)
----- Check
~exists (2:r0=1 /\ 2:r1=0 /\ 3:r0=1 /\ 3:r1=0)

Figure 1–1 HSA01 is forbidden by the consistency of $\xrightarrow{SC_{wg}}$ and $\xrightarrow{coh}$ (Forbidden)

On the web:
http://virginia.cs.ucl.ac.uk/herd/?record=hsa&bell=hsa&cat=hsa&litmus=HSA01
2. Synchronization between units of execution

LISA HSA02
{ 1:r1=−1; }
P0 | P1 ;
w[] x 53 | r[atomic, scacq, wg] r0 y ;
w[atomic, screl, wg] y 1 | mov r3 (neq r0 1) ;
| b r3 Exit1 ;
| r[] r1 x ;
| Exit1: ;
scopes: (wg 0 1)
~exists (1:r0=1 \ 1:r1=0)

Figure 2–1 HSA02 is forbidden by the consistency of \textcolor{red}{\texttt{hhb}} and \textcolor{blue}{\texttt{coh}} (Forbidden)

On the web:
http://virginia.cs.ucl.ac.uk/herd/?record=hsa&bell=hsa&cat=hsa&litmus=HSA02
3. Transitivity with a single scope

LISA HSA03
{ 2:r1=-1; }

P0 | P1 | P2
w[atomic,screl,system] x 1 | r[atomic,scacq,system] r0 y | r[atomic,scacq,system] r0 z ;
| mov r3 (neq r0 1) | mov r3 (neq r0 1) ;
| b r3 Exit1 | b r3 Exit2 ;
| w[atomic,screl,system] z 1 | r[] r1 x ;
| Exit1: | Exit2: ;

scopes: (wg 0 1 2)
¬exists (1:r0=1 \ 2:r0=1 \ 2:r1=0)

Figure 3–1 HSA03 is forbidden by the consistency of hhh and coh (Forbidden)

On the web:
http://virginia.cs.ucl.ac.uk/herd/?record=hsa&bell=hsa&cat=hsa&litmus=HSA03
4. Synchronization through multiple scopes

LISA HSA04
{
1: r1=1; 2: r1=1;
}

P0
<table>
<thead>
<tr>
<th>P1</th>
<th>P2</th>
</tr>
</thead>
<tbody>
<tr>
<td>w[atomic, scacq, wg] y 1</td>
<td>mov r3 (neq r0 1)</td>
</tr>
<tr>
<td>b r3 Exit1</td>
<td>Exit1:</td>
</tr>
<tr>
<td>r[] r1 x</td>
<td>b r3 Exit2</td>
</tr>
</tbody>
</table>

w[atomic, screl, system] z 1 |

r1 x |

w[atomic, screl, system] z 1 |

Exit2: |

Exit1: |

scopes: (agent (wg 0 1) (wg 2))

locations [1: r1;]

~exists (1: r0=1 \ 2: r0=1 \ 2: r1=0)

Figure 4–1 HSA04 is forbidden by the consistency of \( \text{hhb} \) and \( \text{coh} \) (Forbidden)

On the web:

http://virginia.cs.ucl.ac.uk/herd/?record=hsa&bell=hsa&cat=hsa&litmus=HSA04
5. Synchronization through scope inclusion

LISA HSA05
{ 1:r1=1, }
| P0 | P1 |
| w[] x 53 | r[atomic,scacq,agent] r0 y |
| w[atomic,screl,wg] y 1 | mov r3 (neq r0 1) |
| b | r3 Exit1 |
| r[] r1 x |
| Exit1: |

scopes: (wg 0 1)
/~exists (1:r0=1 \ 1:r1=0)

Figure 5-1 HSA05 is forbidden by the consistency of $h_{hb}$ and $c_{oh}$ (Forbidden)

On the web:
http://virginia.cs.ucl.ac.uk/herd/?record=hsa&bell=hsa&cat=hsa&litmus=HSA05
6. Synchronization through scope inclusion and scope transitivity

LISA HSA06
{
  1:r1=-1; 2:r1=-1;
}
P0 | P1 | P2 ;
  w[] x 53 | r[atomic,scacq,agent] r0 y | r[atomic,scacq,system] r0 z ;
w[atomic,screl,wg] y1 | mov r3 (negr01) | mov r3 (negr01) ;
  | b r3 Exit1 | b r3 Exit2 ;
  | r[] r1 x | r[] r1 x ;
  | w[atomic,screl,system] z 1 | Exit2: ;
  | Exit1: |

scopes: {agent (wg 0 1) (wg 2) |
locations [1:r1;] |
~exists (1:r0=1 /\ 2:r0=1 /\ 2:r1=0)

This example is similar to HSA04 in 4 Synchronization through multiple scopes (on page 10), but differs as follows:

- All variables of test HSA06 are in the global segments, while they are in the group segment in example HSA04.
- The scope annotations of the read acquire operation on variable y by unit P1 (event c in Figure 4–1 (on page 10) and Figure 6–1 (below)) differ; it is agent for HSA06 and work-group for HSA04. In that sense, this test HSA06 looks like a combination of the two previous tests (HSA04 and HSA05).

Figure 6–1 HSA06 is forbidden by the consistency of \( \xrightarrow{hhb} \) and \( \xrightarrow{coh} \) (Forbidden)

On the web:
http://virginia.cs.ucl.ac.uk/herd/?record=hsa&bell=hsa&cat=hsa&litmus=HSA06
7. Consistency required for coh and hhb

LISA HSA07
{
  l:r1=-1;
}
P0| P1;
[Equations]
As expected, test HSA07 is forbidden by the consistency of \( \rightarrow_{hhb} \) and \( \rightarrow_{coh} \) (see Figure 7–1 (below)). All previous tests except HSA01 illustrate the consistency of \( \rightarrow_{hhb} \) and \( \rightarrow_{coh} \).

On the web:
http://virginia.cs.ucl.ac.uk/herd/?record=hsa&bell=hsa&cat=hsa&litmus=HSA07

Forbidding this test also results from the value-of-a-load rule. Figure 7–2 (on the next page) shows that the relations \( \rightarrow_{hhb} \) and \( \rightarrow_{coh} \) are consistent. Notice that the arrow \( a \rightarrow_{r} e \) violates the value-of-a-load rule because the read \( e \) does not get its value from the most recent write in \( \rightarrow_{coh} \).
7. Consistency required for coh and hhb

Figure 7–2 HSA07 is forbidden by value-of-a-load rule

a: W(ordinary, rlx, wi) x=52
b: W(ordinary, rlx, wi) x=53
c: W(atomic, screl, system) y=1
d: R(atomic, scacq, system) y=1
e: R(ordinary, rlx, wi) x=52
8. Synchronization between units of execution using relaxed atomics

LISA HSA08
{1:r1=−1;}
P0 | P1 ;
w[] x 53 | r[atomic,rlx,wg] r0 y ;
f[screl,wg] | mov r3 (neq r0 1) ;
| b r3 Exit1 ;
w[atomic,rlx,wg] y 1 | f[scacq,wg] ;
| r[] r1 x ;
| Exit1: ;

scopes: (wg 0 1)
exists (1:r0=1 \ 1:r1=0)

This test illustrates successful synchronization using fences (see Figure 8–1 (below)). In this scenario, fences are enough to restore SC. This is not the case for test HSA11 (see 11 Dekker’s algorithm (on page 18)).

Figure 8–1 HSA08 is forbidden by the consistency of $hhb$ and $coh$ (Forbidden)

On the web:
http://virginia.cs.ucl.ac.uk/herd/?record=hsa&bell=hsa&cat=hsa&litmus=HSA08
9. Unobservable store speculation

LISA HSA09

{ }

P0  | P1     ;
r[] r0 x  | r[] r0 y     ;
mov r3 (neq r0 1) | mov r3 (neq r0 1) ;
b r3 Exit0 | b r3 Exit1 ;
w[] y 1   | w[] x 1 ;
Exit0:    | Exit1: ;

scopes: (wg 0 1)
~exists (0:r0=1 \ 1:r0=1)

Figure 9–1 HSA09 is forbidden by the irreflexivity of $gdo = (\overrightarrow{ido} \cup \overrightarrow{rfe})^+$

On the web:

http://virginia.cs.ucl.ac.uk/herd/?record=hsa&bell=hsa&cat=hsa&litmus=HSA09
10. No out-of-thin-air values

LISA HSA10
{ }
P0 | P1
r[atomic,rlx,system] r0 x | r[atomic,rlx,system] r0 y ;
w[atomic,rlx,system] y r0 | w[atomic,rlx,system] x r0 ;
scopes: (wg 0 1)
¬exists (not (0:r0 = 0) \/ not (1:r0 = 0))

This is the paradigmatic “no values out-of-thin-air” test. As shown in Figure 10–1 (below), the models reject this test by the irreflexivity check of \( gdo \). Observe that the value of events is a variable “S4.” This variable stands for any integer value.

![Diagram](http://virginia.cs.ucl.ac.uk/herd/?record=hsa&bell=hsa&cat=hsa&litmus=HSA10)

Figure 10–1 Test **HSA10** is forbidden by the irreflexivity of \( gdo = (ldo \cup rfe)^+ \)

a: R(atomic,rlx,system) x=S4  c: R(atomic,rlx,system) y=S4

b: W(atomic,rlx,system) y=S4  d: W(atomic,rlx,system) x=S4

On the web:

http://virginia.cs.ucl.ac.uk/herd/?record=hsa&bell=hsa&cat=hsa&litmus=HSA10
11. Dekker’s algorithm

LISA HSA11

\{ \}

\text{P0} \quad | \quad \text{P1} \\
\text{w(atomic,rlx,system)} y 1 \quad | \quad \text{w(atomic,rlx,system)} x 1 \\
\text{r(atomic,rlx,system)} r0 x \quad | \quad \text{r(atomic,rlx,system)} r0 y \\

scopes: (wg 0 1) \\
exists (0:r0 = 0 \land 1:r0 = 0)

Figure 11-1 Test HSA11 is allowed

On the web:

http://virginia.cs.ucl.ac.uk/herd/?record=hsa&bell=hsa&cat=hsa&litmus=HSA11

Figure 11-2 Test HSA11+fences is allowed

On the web:

http://virginia.cs.ucl.ac.uk/herd/?record=hsa&bell=hsa&cat=hsa&litmus=HSA11+fences
12. Conflict without synchronization

LISA HSA12
{ }
P0 | P1 ;
w[] x 1 | r[] r0 x ;
scopes: (wg 0 1)
exists (1:r0=1)

This test illustrates an ordinary race. There is no \( \rightarrow \)-induced order between events \( a \) and \( b \), which are to the same location (by different units), with one event (\( a \)) being a write (see Figure 12–1 (below)).

Figure 12–1 Test HSA12 is racy

a: W(ordinary,rb,wi) x=1
b: R(ordinary,rb,wi) x=1

On the web:
http://virginia.cs.ucl.ac.uk/herd/?record=hsa&bell=hsa&cat=hsa&litmus=HSA12
13. Insufficient scope

LISA HSA13
{ 1:r1←1; }

P0 | P1 ;
wx 1 | r[atomic,scacq,wg] r0 y ;
wx[atomic, screl, wg] y 1 | mov r3 (neq r0 1) ;
| b r3 Exit1 ;
| r[] r1 x ;
| Exit1: ;

scopes: (agent 0 1)
exists (1:r0=1 \ 1:r1=1)

This test illustrates a special race due to non-matching scopes:

- Figure 13–1 (below) shows two races. One is between atomic events b and c and stems from b and c belonging to different work-groups, while bearing the wg scope annotation.
- Figure 13–2 (below) depicts the relations \( \text{same} \leftarrow \text{wg} \) and \( \text{matches} \), which do not relate b and c. Pairs related by \( \text{matches} \) are subtracted from potential special races.

Because b and c are in different work-groups, events a and d are not ordered by \( \text{hbb} \) (which reduces to \( \text{pol} \)), resulting in a second (ordinary) race.

Figure 13–1 Test HSA13 is racy

Figure 13–2 Scopes for test HSA13

On the web:
http://virginia.cs.ucl.ac.uk/herd/?record=hsa&bell=hsa&cat=hsa&litmus=HSA13