# EENG 426/CPSC 459/ENAS 876
# Silicon Compilation

**Production rule synthesis**

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Fall 2018

# Convert HSE to PRS

Transforms a handshaking expansion into a set of production rules.

- state assignment
- guard strengthening
- symmetrization

May have to reshuffle to improve production rules!

# Convert HSE to PRS

CHP:

$$*[[\overline{L} \longrightarrow R; L]]$$

Handshaking:

$L$: passive, since it is probed.

$R$: active, since matches passive $L$

$$*[[li]; ro\uparrow; [ri]; ro\downarrow; [\neg ri]; lo\uparrow; [\neg li]; lo\downarrow]$$

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# Syntactic guards

We begin with a production rule set that is syntactically derived from the original program:

$$
\begin{array}{rcl}
li & \mapsto & ro\uparrow \\
ri & \mapsto & ro\downarrow \\
\neg ri & \mapsto & lo\uparrow \\
\neg li & \mapsto & lo\downarrow
\end{array}
$$

Each action is guarded by the wait immediately before it.

If the handshaking expansion is deadlock-free, it is always possible to execute the syntactic production rules in program order.

# Syntactic guards

Other execution orders may be possible!

Example:

$$\begin{aligned} \neg ri &\mapsto lo\uparrow \\ \neg li &\mapsto lo\downarrow \end{aligned}$$

can fire in the initial state.

# Strengthening

To prevent incorrect firings, we must reduce the number of states in which a production rule can fire by strengthening the guard.

The guard must be strong enough to uniquely identify the state(s) of the handshaking expansion in which the rule must fire.

Where can $ri \mapsto lo\uparrow$ fire?

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State of the circuit as a vector $(li, lo, ri, ro)$:

$$
\begin{aligned}
*[\,&\{X000\}\,[li]\,;\,\{1000\}\,ro\uparrow;\,\{10X1\}\,[ri]\,;\,\{1011\}\,ro\downarrow;\\
&\{10X0\}\,[\neg ri]\,;\,\{1000\}\,lo\uparrow;\,\{X100\}\,[\neg li]\,;\,\{0100\}\,lo\downarrow\\
]&
\end{aligned}
$$

Environment:

$$
\begin{aligned}
&*[\ \ li\uparrow;\,[lo]\,;\,li\downarrow;\,[\neg lo]\ \ ]\\
\|&\\
&*[\ \ [ro]\,;\,ri\uparrow;\,[\neg ro]\,;\,ri\downarrow\ \ ]
\end{aligned}
$$

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# Systematic approach

States in which $\neg ri \mapsto lo\uparrow$ can fire:

$$*[\bullet[li];\bullet ro\uparrow;\bullet[ri];ro\downarrow;\bullet[\neg ri];\bullet lo\uparrow;\bullet[\neg li];\bullet lo\downarrow]$$

States in which $\neg ri \mapsto lo\uparrow$ has effective firings:

$$*[\bullet[li];\bullet ro\uparrow;\bullet[ri];ro\downarrow;\bullet[\neg ri];\bullet lo\uparrow;[\neg li];lo\downarrow]$$

States in which $\neg ri \mapsto lo\uparrow$ has undesirable effective firings:

$$*[\bullet[li];\bullet ro\uparrow;\bullet[ri];ro\downarrow;[\neg ri];lo\uparrow;[\neg li];lo\downarrow]$$

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# Systematic approach

States in which $\neg ri \mapsto lo\uparrow$ has undesirable effective firings or could pcause interference (conflicting set):

$$*[\bullet[li]; \bullet ro\uparrow; \bullet[ri]; ro\downarrow; [\neg ri]; lo\uparrow; [\neg li]; \bullet lo\downarrow]$$

States in which $\neg ri \mapsto lo\uparrow$ must fire:

$$*[[li]; ro\uparrow; [ri]; ro\downarrow; \bullet[\neg ri]; \bullet lo\uparrow; [\neg li]; lo\downarrow]$$

$\Rightarrow$ select guard so that this is the case.

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# Guard strengthening

Consider $B \mapsto x\uparrow$

HSE:

$$\ldots;\ \ x\uparrow;\ \ \ldots;\ \ x\downarrow;\ \ \ldots;\ \ x\uparrow;$$

firing set: set of states in which the rule could fire. (Determined by $B$)

disallowed set: set of states in which the production rule firing is not allowed because of interference or violation of HSE

Conflicting set: intersection of firing and disallowed set, should be empty!

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# State variables

Sometimes it is not possible to identify each state uniquely using the variables we have in the handshaking expansion.

$\ldots.; \;\; xo{\uparrow}; [xi]; xo{\downarrow}; [\neg xi]; \;\; \ldots$

Solution: introduce a new variable that has different values in the two indistinguishable states.

There are several places where the assignment to the state variable can be inserted.

# State variables

Handshaking: vector ($li, lo, ri, ro$)

$* [\{X000\}\,[li]\,;\,\{1000\}ro\uparrow;\,\{10X1\}\,[ri]\,;\,\{1011\}ro\downarrow;$
$\{10X0\}\,[\neg ri]\,;\,\{1000\}lo\uparrow;\,\{X100\}\,[\neg li]\,;\,\{0100\}lo\downarrow$
$]$

After state-variable insertion: vector ($x, li, lo, ri, ro$)

$x\downarrow;$
$* [\{0X000\}\,[li]\,;\,\{01000\}ro\uparrow;\,\{010X1\}\,[ri]\,;\,\{01011\}x\uparrow;$
$\{11011\}ro\downarrow;\,\{110X0\}\,[\neg ri]\,;\,\{11000\}lo\uparrow;\,\{1X100\}\,[\neg li]\,;$
$\{10100\}x\downarrow;\{00100\}lo\downarrow$
$]$

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# Production rule generation

HSE:

$$x{\downarrow};$$
$$*[\,[li]\,;ro{\uparrow};\ [ri]\,;x{\uparrow};\ ro{\downarrow};\ [\neg ri]\,;lo{\uparrow};\ [\neg li]\,;x{\downarrow};\ lo{\downarrow}]$$

PRS:

$$\begin{array}{rcl}
\neg x \wedge li & \mapsto & ro{\uparrow} \\
ri & \mapsto & x{\uparrow} \\
x & \mapsto & ro{\downarrow} \\
x \wedge \neg ri & \mapsto & lo{\uparrow} \\
\neg li & \mapsto & x{\downarrow} \\
\neg x & \mapsto & lo{\downarrow}
\end{array}$$

# Symmetrization

$$\begin{aligned} x \wedge \neg ri &\mapsto lo\uparrow \\ \neg x &\mapsto lo\downarrow \end{aligned}$$

Turn into combinational logic:

$$\begin{aligned} ri \vee \neg x &\mapsto lo\downarrow \\ \neg li \vee x &\mapsto ro\downarrow \end{aligned}$$

Why is this legal?

# Symmetrization

Replacing a state-holding operator with a combinational one:

$$\begin{aligned} x \wedge \neg B &\mapsto z\uparrow \\ B &\mapsto z\downarrow \end{aligned}$$

If $B$ holds as a precondition of $\neg x$, we can replace the second rule with:

$$\neg x \vee B \mapsto z\downarrow$$

We must ensure that no new effective firings have been introduced, i.e.,

$$x \vee B \vee \neg z$$

is invariant.

# Operator reduction

The last step consists of grouping together production rules into operators, and identifying standard operators in the production rule set.

$$\begin{aligned} li \wedge ri &\mapsto x\uparrow \\ \neg ri \wedge \neg li &\mapsto x\downarrow \end{aligned}$$

$$\begin{aligned} \neg x \wedge li &\mapsto ro\uparrow \\ \neg li \vee x &\mapsto ro\downarrow \end{aligned}$$

$$\begin{aligned} x \wedge \neg ri &\mapsto lo\uparrow \\ ri \vee \neg x &\mapsto lo\downarrow \end{aligned}$$