SIS – Logic Synthesis System

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Introduction

- *Logic Synthesis* performs the translation from a RTL description (e.g., VHDL) into a design implementation in terms of logic gates, and optimizes the latter
  - It may be driven by different cost functions
    - Area
    - Delay, clock speed
    - etc.
  - It leads to implementations meeting the desired objectives

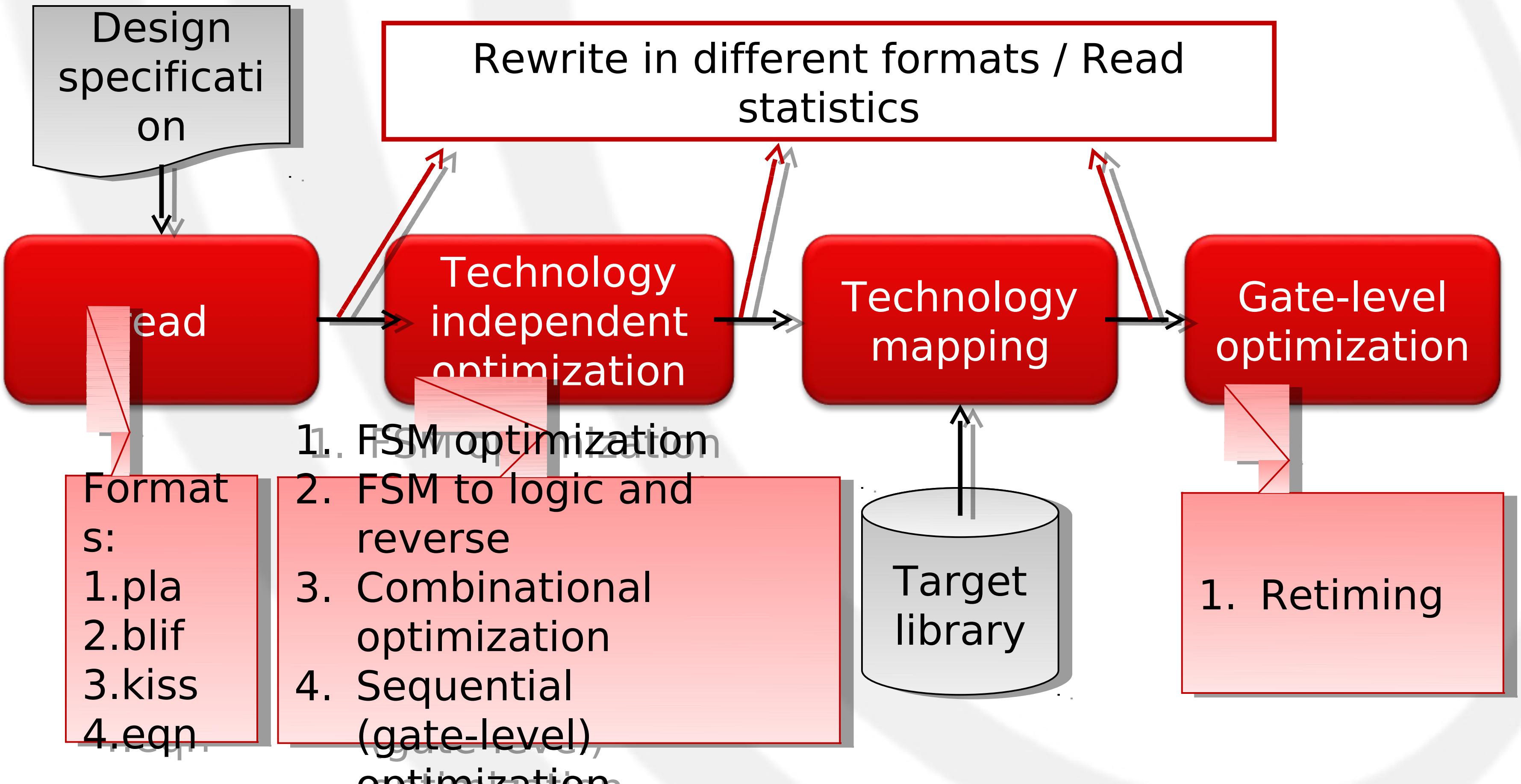
SIS – Logic Synthesis System (I)

- *SIS* is an interactive tool for synthesis and optimization of sequential circuits
  - developed by the CAD group of U.C. Berkeley in the 1990s
- It produces an optimized net-list preserving the sequential input/output behavior
- It incorporates a set of logic optimization algorithms
  - users can choose among a variety of techniques at each stage of the synthesis process

SIS – Logic Synthesis System (II)

- Different algorithms for various stages of sequential synthesis:
  - State minimization
  - State assignment
  - Node simplification
  - Kernel and cube extraction
  - Technology mapping
  - Retiming

How to use *SIS*



Design Specification

- A sequential circuit can be input to *SIS* in several ways allowing *SIS* to be used at various stages of the design process
- The most common entry points are
  - Net-list of gates
  - Truth table in PLA (espresso) format
  - Set of equations
  - Finite-state machine in

Logic Implementation (Net-list)

- The net-list description is given in extended *BLIF* (Berkeley Logic Interchange Format)
- It consists of interconnected single-output combinational gates and latches
  - Gates are simple elements that perform logical operations
  - Latches store the state

The SIS Synthesis and Optimization System – Read the specifications

- $> sis
  UC Berkeley, SIS 1.3.6 (compiled 2010-11-14 12:35:42)
  sis>
- sis> *help*
  - returns a list of all the commands provided by SIS
- sis> *read_pla* <file_name>
  - Loads a pla description
- sis> *read_blif* <file_name>
  - Loads a net-list description
- sis> *read_eqn* <file_name>
  - Loads an equation-based description
- sis> *read_kiss* <file_name>
  - Loads a kiss-style STG description

The SIS Synthesis and Optimization System – Write the specifications

- sis> *write_pla* [file_name]
  - Writes a PLA description
- sis> *write_blif* [file_name]
  - Writes a net-list description
- sis> *write_eqn* [file_name]
  - Writes an equation-based description
- sis> *write_kiss* [file_name]
  - Writes a kiss-style STG description

Example 1: the full-adder

```
# full-adder circuit
.i 3
.o 2
.ilb x y z
.ob C S
000 00
001 01
010 01
011 10
100 01
101 10
110 10
111 11
.end
```

- Create a .pla file with the description
- Open the file in SIS
- Try the following commands:
  - print
  - print_stats
  - print_io

The SIS Synthesis and Optimization System – Node simplification (II)

- In *SIS*, the user may invoke the *ESPRESSO* program to perform node simplification
- sis> *full_simplify*
  - the input is a net-list (blif or PLA format)
  - returns a minimized net-list (blif format)
    - SIS decomposes multiple output functions into single output functions and represents them separately

The SIS Synthesis and Optimization System – Node Restructuring

- A logical network can be modified by
  - Creating new nodes
  - Deleting nodes
  - Creating new connections
  - Deleting connections
- A particular case of node restructuring is node creation by extracting a factor from one or more nodes

The SIS Synthesis and Optimization System – Kernel (I)

- The extraction of new nodes that are factors of existing nodes is a form of division that may be performed in the Boolean or algebraic domain
- Algebraic techniques: sum-of-products are treated as standard polynomials
  - look for expressions that are observed many times in the nodes of the network and extract such common expressions
  - The extracted expression is implemented only once and the output of that node replaces the expression in any other node
- Current algebraic techniques used in SIS are based on cube-free divisors called *kernels*

The SIS Synthesis and Optimization System – Kernel (II)

- An expression *f* is cube-free if no cubes divides the expression evenly
  - ab + c is cube free
  - ab+ac or abc are not cube free
- The primary divisors of an expression are obtained by dividing the expression by cubes
- The kernels of an expression are the cube-free primary divisors of the expression

The SIS Synthesis and Optimization System – Kernel (III)

- adf+aef+bdf+bef+cdf+cef+g = (a+b+c)(d+e)f+g

Kernel	Cokernel
a+b+c	df, ef
d+e	af, bf, cf
(a+b+c)(d+e)	f
(a+b+c)(d+e)f+g	1

The SIS Synthesis and Optimization System – Kernel (IV)

- In *SIS*, the user may invoke the command *fast_extract*, i.e., *fx*, to perform kerneling
- sis> *fx*
  - the input is a net-list
  - extracts common expressions among the nodes and rewrites the nodes of the network in terms of common expressions

The SIS Synthesis and Optimization System – Technology mapping (I)

- A tree-covering algorithm is used to map arbitrary complex logic gates into cells available in a technology library
- Technology mapping consists of two phases:
  - Decomposing the logic to be mapped into a network of 2-input NAND gates and inverters
  - Covering the network by patterns that represent the possible cells in the library
    - During the covering stage the area or the delay of the circuit is used as an optimization criterion

The SIS Synthesis and Optimization System – Technology mapping (II)

- In *SIS*, the user may invoke the command *rlib* and *map* to select a library for the technology mapping and perform the mapping, respectively
- sis> *rlib* <library_name>
  sis> *map*
  - the input is a net-list (blif format)
  - map complex logic gates into cells of the chosen technology library (genlib format)

Mapping the full adder

- Load the *minimal.genlib* library
- Map the full-adder to the library
- Try the following commands:
  - print
  - print_gate
  - print_map_stats

Example 2: the ticket machine

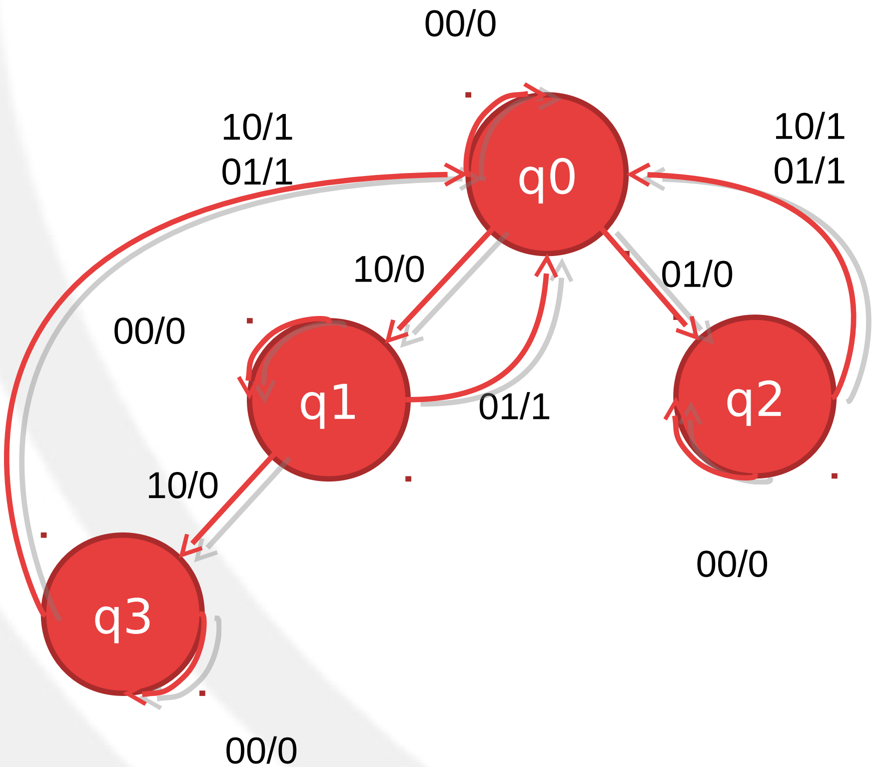
- Print a ticket after 1.50 euros are deposited
- Single slot for 1 euro and 50 cents coins
- No change

State Transition Graph (STG) (I)

- A state transition table for a finite-state machine is specified using the KISS format
- It is used in state assignment and state minimization programs
- STG
  - States are symbolic
  - The transition table indicates the next symbolic state and output bit-vector given a current state and an input bit-vector
  - Don't care conditions are indicated by a missing transition or by a '**-**' in an output bit
    - A present-state/input combination has no explicit next-state/output, or
    - For a present-state/input combination a '-' output stands for either 0 or 1

State Transition Graph (STG) (II)

```
.start_kiss
.i 2
.o 1
.r q0
00 q0 q0 0
10 q0 q1 0
01 q0 q2 0
00 q1 q1 0
10 q1 q3 0
01 q1 q0 1
00 q2 q2 0
10 q2 q0 1
01 q2 q0 1
00 q3 q3 0
10 q3 q0 1
01 q3 q0 1
.end_kiss
.end
```



The SIS Synthesis and Optimization System – State minimization (I)

- State minimization works on STGs
  - Degrees of freedom (i.e., unspecified transitions or explicit output don’t cares) can be exploited to produce a machine with fewer states
- State minimization looks for equivalent states in order to minimize the total number of states
  - Two states are equivalent if they produce the same output sequences given the same input sequences

The SIS Synthesis and Optimization System – State minimization (II)

- In *SIS*, the user may invoke the *STAMINA* program to perform state minimization
  - STAMINA is a state minimizer for incompletely specified machine
- sis> *state_minimize* stamina
  - the input is a STG (kiss format)
  - the original STG is replaced by the one computed by STAMINA with (possibly) fewer states

Minimize the Ticket counter FSM

- Create a .kiss2 file with the description of the FSM
- Open the file in SIS
- Minimize the FSM
- Compare the minimized machine with the original one
  - use write_kiss to print the minimized FSM

The SIS Synthesis and Optimization System – State assignment (I)

- State assignment provides the mapping from a STG to a net-list
- State assignment requires a state transition table and computes binary codes for each symbolic state
- Binary codes are used to create a logic level implementation
  - substituting the binary codes for the symbolic states, it creates a latch for each bit of the binary code

The SIS Synthesis and Optimization System – State assignment (II)

- In *SIS*, the user may invoke either *JEDI* or *NOVA* programs to perform state assignments
- sis> *state_assign* nova
  or
  sis> *state_assign* jedi
  - the input is a STG (kiss format)
  - returns a state assignment of the STG and a corresponding logic implementation (net-list) (blif format)

State-assign the Ticket counter FSM

- Do the state assignment of the minimized FSM
  - Use *print*, *print_stats*, and *print_latch* to obtain information
- Simulate the FSM
  - Use *simulate input1 input2* to give inputs
  - *print_state* gives the current state of the FSM
- Compare the results of *jedi* and *nova*

Mapping the ticket counter

- Load the *lib2.genlib* and the *lib2_latch.genlib* libraries
  - Use *rlib –a* to load the second library!
- Map the ticket counter FSM
- Try the following commands:
  - print_stats
  - print_gate
  - print_map_stats

The SIS Synthesis and Optimization System – Retiming (I)

- Retiming is an algorithm that moves registers across logic gates to minimize
  - Cycle time, or
  - Number of registers, or
  - Number of registers subject to a cycle-time constraint
- It operates on synchronous edge-triggered designs
- The sequential I/O behavior of the circuit is maintained

The SIS Synthesis and Optimization System – Retiming (II)

- In *SIS*, the user may invoke the command *retime* to perform the retiming of the circuit
- sis> *retime*
  - the input is a net-list (blif format)
  - Add more latches, or re-position the latches, to reduce the clock period
    - Generally used to reduce the cycle time of the circuit by adding latches

Retiming the ticket counter

- Use the command *retime* to optimize the circuit
- Try the following commands:
  - print_stats
  - print_gate
  - print_map_stats
- Simulate the new circuit

Synthesis and optimizations

- SIS provides scripts for performing logic network optimizations
  - The standard *script*
  - The standard *script.rugged*
  - The standard *script.delay*
- Such scripts derive from the experience of SIS developers

References – U.C. Berkeley

- More *SIS* infos are available at http://embedded.eecs.berkeley.edu/pubs/downloads/sis/index.htm
  - Documentation
  - Examples