Evaluation of numerical results
Decomposition of binary (MCNC) benchmarks

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Table 3.2: MVDD and MBDD size comparisons.
Top Down algorithm comparison with Jozwiak's algorithm.
SBSD comparison to FLASH on Wright Lab benchmark functions.
APPLICATIONS

- FPGA SYNTHESIS
- VLSI LAYOUT SYNTHESIS
- DATA MINING AND KNOWLEDGE DISCOVERY
- MEDICAL DATABASES
- EPIDEMIOLOGY
- ROBOTICS
- FUZZY LOGIC DECOMPOSITION
- CONTINUOUS FUNCTION DECOMPOSITION
Example of a application

VLSI Layout
Layout decomposition block diagram.
Number of complex gates with limited serial transistors

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<td>1 1 2 3 4 5</td>
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<td>2 7 18 42 90</td>
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<td>3</td>
<td>3 18 87 396 1677</td>
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<td>4 42 396 3503 28435</td>
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<tr>
<td>5</td>
<td>5 90 1677 28435 125803</td>
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VLSI layout of $\overline{f} = \overline{d(a + c)} + (b + c)(\overline{bd})$. 
# Comparison of SIS and COMPLEX

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<th>COMPLEX</th>
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Example of decomposition based synthesis for lattice diagrams.
Example of a application
Synthesis for FPGAs
XILINX Field Programmable Gate Array
Configurable Logic Block

DATA IN .di

LOGIC VARIABLES
.a
.b
.c
.d
.e

ENABLE CLOCK .ec

CLOCK .K

RESET .rd

“1” (ENABLE)

“0” (INHIBIT)
(GLOBAL RESET)

OR

COMBINATORIAL FUNCTION

MUX1

MUX1

QX

QY

0 MUX 1

0 MUX 1

D

Q

RD

RD

CLB OUTPUTS .Y

.X

CLB OUTPUTS
Interconnections

PROGRAMMABLE LOCAL INTERCONNECTIONS

GLOBAL INTERCONNECTION

CONFIGURABLE LOGIC BLOCKS

CONFIGURABLE INTERCONNECTION MATRIX
complete decomposition system.
Example of a application

Knowledge discovery in data with no error
Michalski’s Trains

1. TRAINS GOING EAST

1.

2.

3.

4.

5.

2. TRAINS GOING WEST

1.

2.

3.

4.

5.
Michalski’s Trains

• Multiple-valued functions.
• There are 10 trains, five going East, five going West, and the problem is to find the simplest rule which, for a given train, would determine whether it is East or Westbound.
• The best rules discovered at that time were:
  – 1. If a train has a short closed car, then it Eastbound and otherwise Westbound.
  – 2. If a train has two cars, or has a car with a jagged roof then it is Westbound and otherwise Eastbound.
• Espresso format. MVGUD format.
Michalski’s Trains

.type mv
.i 32
.o 1
.ilb size load w0 10 s0 n0 ls0 w1 l1 s1 n1 ls1 w2 l2 s2 n2 ls2 w3 l3 s3 n3 ls3
    a b c d e f g h i j
.ob direction
.imv 3 4 2 2 10 4 4 2 2 10 3 4 2 2 7 3 4 2 2 8 2 3 2 2 2 2 2 2 2 2 2
.omv 2
 2 3 0 1 6 3 2 0 0 8 1 3 1 1 6 1 1 0 0 6 1 0 0 1 0 0 1 0 0 1 0
 1 2 0 9 1 3 0 0 7 1 2 0 0 0 2 0 -- -- -- -- 0 1 0 1 0 0 0 0 0 0
 1 1 0 0 6 1 0 0 0 4 1 3 1 1 0 1 3 -- -- -- -- 0 0 0 0 1 0 1 0 0 0

Michalski’s Trains

.data

.i number of input variables (attributes)
.o number of output variables (attributes)

where:
.ilb input variable names
.od output variable names
.imv cardinalities of input variables
.omv cardinalities of output variables

Variables 1-2: general attributes
.size number of cars (integer in [3-5])
.load number of different loads (integer in [1-4])

Variables 3-22: 5 attributes for each of cars 2 through 5: (20 attributes total)
.w number of wheels (integer in [2-3])
.l length (short or long)
.s shape (closedrect, oblongrect, circle, engine, hexagon, jaggedtop, openrect, opentrap, slopedtop, unshaped)
.n number of loads (integer in [0-3])
.ls load shape (circled, hexagon, rectangle, triangle)

Variables 23-32: 10 Boolean attributes describing whether 2 types of loads are on adjacent cars of the train
.a rectangle next to rectangle (0 if false, 1 if true)
.b rectangle next to triangle (0 if false, 1 if true)
.c rectangle next to hexagon (0 if false, 1 if true)
.d rectangle next to circle (0 if false, 1 if true)
.e triangle next to triangle (0 if false, 1 if true)
.f triangle next to hexagon (0 if false, 1 if true)
.g triangle next to circle (0 if false, 1 if true)
.h hexagon next to hexagon (0 if false, 1 if true)
.i hexagon next to circle (0 if false, 1 if true)
.j circle next to circle (0 if false, 1 if true)
Michalski’s Trains

- Attribute 33: Class attribute (east or west)
  - direction (east = 0, west = 1)
- The number of cars vary between 3 and 5. Therefore, attributes referring to properties of cars that do not exist (such as the 5 attributes for the “5th” car when the train has fewer than 5 cars) are assigned a value of “-”.
- Applied to the trains problem our program discovered the following rules:
  - 1. If a train has triangle next to triangle or rectangle next to triangle on adjacent cars then it is Eastbound and otherwise Westbound.
  - 2. If the shape of car 1 (s1) is jagged top or open rectangle or u-shaped then it is Westbound and otherwise Eastbound.
MV benchmarks: zoo

MVFC = 25^2 \times 15 \\
\quad t = 9.9s \\
\quad MVFC = 197
MV benchmarks: shuttle

MVFC = 256  t = 1.8s  MVFC = 51
MV benchmarks: lenses

MVFC = 38

age
spect
astigm
tears

3
2
2
3

lenses

\equiv

age
spect
astigm
tears

3
2
2

3

lenses

MVFC = 30

t = 0.3s
Example of a application

Medical data bases with error
Evaluation of results for learning

1. Learning Error

\[ \text{error} = \frac{\# \text{ of incorrectly classified samples}}{\text{total \# of samples}} \]

2. Occam Razor, complexity
A machine learning approach versus several logic synthesis approaches

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<th>Average Error</th>
<th>Number of Samples</th>
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Finding the error, DFC, and time of the decomposer on the benchmark \textit{kdd5}.
The average error over 54 benchmark functions.
MV benchmarks: breastc

MVFC = 10^9  t = 1880s  MVFC = 496
Example of a application

Data mining system for epidemiologists
Binning Strategy #1: Linear Mapping

Continuous Data

Bin 1 := [0, 2)
Bin 2 := [2, 4)
Bin 3 := [4, 6)
Bin 4 := (6, 8]
Bin 5 := [8, 10]

Discrete Data

Discrete Value

Value of instance

Sample Number

Sample Number
Epidemiological Survey

Race:
_____ (W) White
_____ (B) Black
_____ (O) Other

Did you [Name of child] have contact with or change any diapers while at Battleground State Park?

_____ (1) YES _____ (2) NO _____ (9) DK

Estimate the amount of time you [Name of child] spent in the water (total time):
> 2 hours _____ (3)
15 minutes – 2 hours _____ (2)
< 15 minutes _____ (1)

How serious was your child’s illness?
_____ (1) No illness _____ (2) diarrhea but no fever _____ (3) diarrhea and fever _____ (9) DK
## Survey Encoding

### Input Variable ‘a’
- White encodes to ‘0’
- Black encodes to ‘1’
- Other encodes to ‘2’

### Input Variable ‘c’
- 2 hr < encodes to ‘2’
- [.25, 2) hr encodes to ‘1’
- < .25 hr encodes to ‘0’

### Input Variable ‘b’
- DK encodes to ‘2’
- NO encodes to ‘1’
- YES encodes to ‘0’

### Output Variable ‘z’
- Don’t Know encodes to ‘3’
- Diarrhea and fever encodes to ‘2’
- Diarrhea but no fever encodes to ‘1’
- No illness encodes to ‘0’
<table>
<thead>
<tr>
<th>Race:</th>
<th>White</th>
<th>Black</th>
<th>Other</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(W)</td>
<td>(B)</td>
<td>(O)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Did you [Name of child] have contact with or change any diapers while at Battleground State Park?</th>
</tr>
</thead>
<tbody>
<tr>
<td>(1) YES (2) NO (9) DK</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Estimate the amount of time you [Name of child] spent in the water (total time):</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt; 2 hours (3)</td>
</tr>
<tr>
<td>15 minutes – 2 hours (2)</td>
</tr>
<tr>
<td>&lt; 15 minutes (1)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>How serious was your child’s illness?</th>
</tr>
</thead>
<tbody>
<tr>
<td>(1) No illness (2) diarrhea but no fever (3) diarrhea and fever (9) DK</td>
</tr>
<tr>
<td>Sample #</td>
</tr>
<tr>
<td>----------</td>
</tr>
<tr>
<td>0</td>
</tr>
</tbody>
</table>
## Ten Encoded Surveys

<table>
<thead>
<tr>
<th>Sample #</th>
<th>a</th>
<th>b</th>
<th>c</th>
<th>z</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1</td>
<td>0</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>1</td>
<td>2</td>
<td>1</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>2</td>
<td>2</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>3</td>
<td>0</td>
<td>2</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>4</td>
<td>2</td>
<td>1</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>5</td>
<td>2</td>
<td>2</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>6</td>
<td>0</td>
<td>2</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>7</td>
<td>0</td>
<td>2</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>8</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>9</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0</td>
</tr>
</tbody>
</table>

Multi-valued Relation Represented Tabular Form
Market

- **Current intended market**
  - State and federal epidemiologists working within the United States of America.

- **Anticipated market demand**
  - There are approximately 1000 epidemiologists in the United States.

- **Predicable future markets**
  - Any application where there is a data set with many unknown values and a user that wishes to generate hypothesis from the data.
Competition

- **Oracle’s Darwin®**
  - Darwin’s one-click data import wizards accept data in all popular formats, including ODBC, ASCII, and SAS
  - Array of techniques increases modeling accuracy. These techniques include regression trees, neural networks, $k$-nearest neighbors, regression, and clustering algorithms

- **Wizsoft’s WizRule**
  - Reports the rules, and the cases deviating from the norm
  - Sorts the deviated cases by their level of unlikelihood

- **Information Discovery’s Data Mining Suite**
  - Uses relational and multi-dimensional data
  - Results are delivered to the user in plain English, accompanied by tables and graph that highlight the key patterns

- **Center for Disease Control’s Epi Info**
  - Tailored for Epidemiologist
  - DOS based suite of Application
Flow of the Program

Delimited data file

Header file

Yes

No

Does the user already have a Header file?

Header Wizard

Module 1

Yes

No

Change header file?

Preprocessor

Module 3

Yes

No

Re-bin continuous data?

Binning Software

Module 4

Yes

No

Decomposer

Module 5

Yes

No

Output formatter

Module 6

Yes

No

K-map

BDD Netlist

Module 2

Input file formatting Wizard

Module 4 Binning Software

Is another iterations required?
Example of a application

Gait control of a robot puppet for Oregon Cyber Theatre
Model with a gripper
Model with an internet camera
Spider I control
- phase five:

**supercomputer**

Universal Logic Machine

DecStation

 Turbochannel
teaching a hexapod to walk
The following formula describes the exact motion of the shaft of every servo.

\[ \theta_i(t) = \theta_o + A_i \sin(\omega_i \cdot t + \phi_i) \]

- Theta, the angle of the servo’s shaft, is a function of time.
- Theta naught is a base value corresponding to the servo’s middle position. Theta naught will be the same for all the servos.
- ‘A’ is called the amplitude of the oscillation. It relates to how many degrees the shaft is able to rotate through.
- Omega relates to how fast the servo’s shaft rotates back and forth. Currently, for all servos, there are only four possible value that omega may take.
- Phi is the relative phase angle.
And a familiar table again

<table>
<thead>
<tr>
<th>Trial</th>
<th>Servo 1</th>
<th>…</th>
<th>Servo 12</th>
<th>x</th>
<th>y</th>
<th>z</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Amp</td>
<td>Freq</td>
<td>Phase</td>
<td>Amp</td>
<td>Freq</td>
<td>Phase</td>
</tr>
<tr>
<td>1</td>
<td>0</td>
<td>1</td>
<td>4</td>
<td>1</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>…</td>
<td>…</td>
<td>…</td>
<td>…</td>
<td>…</td>
<td>…</td>
<td>…</td>
</tr>
<tr>
<td>n</td>
<td>1</td>
<td>1</td>
<td>5</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>
Conclusion

• Stimulated by practical hard problems:
  – Field Programmable Gate Arrays (FPGA),
  – Application Specific Integrated Circuits (ASIC)
  – high performance custom design (Intel)
  – Very Large Scale of Integration (VLSI) layout-driven synthesis for custom processors,
  – robotics (hexapod gaits, face recognition),
  – Machine Learning,
  – Data Mining.
Conclusion

• Developed 1989-present
• A set of tools for decomposition of binary and multi-valued functions and relations.
• Extended to fuzzy logic, reconstructability analysis and real-valued functions.
Conclusion

- Our recent software allows also for bi-decomposition, removal of vacuous variables and other preprocessing/postprocessing operations.
- Variants of our software are used in several commercial companies.
- The applications of the method are unlimited and it can be used whenever decision trees or artificial neural nets are used now.
- The quality of learning was better than in the top decision tree creating program C4.5 and various neural nets.
- The only problem that remains is speed in some applications.
Conclusion

- **On our WWW page,**
  
  http://www.ee.pdx.edu/~cfiles/papers.html

  the reader can find many benchmarks from various disciplines that can be used for comparison of machine learning and logic synthesis programs.

- We plan to continue work on decomposition and its various practical applications such as epidemiology or robotics which generate large real-life benchmarks.

- We work on FPGA-based reconfigurable hardware accelerator for decomposition to be used on a mobile robot.