Microfluidic Very Large Scale Integration (VLSI)
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Microfluidic Very Large Scale Integration (VLSI)
Modeling, Simulation, Testing,
Compilation and Physical Synthesis

Springer
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# Acronyms

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<th>Description</th>
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<tr>
<td>ACCENT</td>
<td>A Compiler Compiler for the ENTire class of context-free languages</td>
</tr>
<tr>
<td>ALAP</td>
<td>As Late As Possible</td>
</tr>
<tr>
<td>ALL</td>
<td>Adaptive Left-to-right Leftmost derivation (parsing algorithm)</td>
</tr>
<tr>
<td>ANTLR</td>
<td>ANOther Tool for Language Recognition</td>
</tr>
<tr>
<td>ASAP</td>
<td>As Soon As Possible</td>
</tr>
<tr>
<td>ATPG</td>
<td>Automatic Test Pattern Generation</td>
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<tr>
<td>CAD</td>
<td>Computer Aided Design</td>
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<tr>
<td>CL</td>
<td>Candidate List</td>
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<tr>
<td>CP</td>
<td>Constraint Programming</td>
</tr>
<tr>
<td>CPA</td>
<td>Colorimetric Protein Assay</td>
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<tr>
<td>CPAM</td>
<td>Constraint Programming-Based Application Mapping</td>
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<tr>
<td>CSR</td>
<td>Combined Scheduler and Router</td>
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<tr>
<td>DAG</td>
<td>Directed Acyclic Graph</td>
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<tr>
<td>DNA</td>
<td>Deoxyribose Nucleic Acid</td>
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<td>EA</td>
<td>Example Application</td>
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<td>EWOD</td>
<td>Electrowetting-on-dielectric</td>
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<td>GCP</td>
<td>Graph Coloring Problem</td>
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<td>GE</td>
<td>General Electric</td>
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<tr>
<td>GPA</td>
<td>General Purpose Actuation</td>
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<tr>
<td>GRASP</td>
<td>Greedy Random Adaptive Search Procedure</td>
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<tr>
<td>GUI</td>
<td>Graphical User Interface</td>
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<tr>
<td>HA</td>
<td>Hadlock’s Algorithm</td>
</tr>
<tr>
<td>HC</td>
<td>Hill Climbing</td>
</tr>
<tr>
<td>HIV</td>
<td>Human Immunodeficiency Virus</td>
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<tr>
<td>HLS</td>
<td>High Level Synthesis</td>
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<tr>
<td>ID</td>
<td>Identifier</td>
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IDE  Integrated Design Environment
ISI  Institute for Scientific Information
ITRS  International Technology Roadmap for Semiconductors
IVD  In-Vitro Diagnosis
JSON  Java Script Object Notation
LALR  Look Ahead Left-to-right Rightmost derivation
LL  Left-to-right Leftmost derivation
LR  Left-to-right Rightmost derivation
LS  List Scheduling
LSAM  List Scheduling-Based Application Mapping
LSI  Large-Scale Integration
MHDL  microfluidic Hardware Description Language
MI  Microfluidic Innovations
MiS  Multilevel logic Synthesis
mLSI  microfluidic Large-Scale Integration
MOS  Metal Oxide Semiconductor
MOSFET  Metal Oxide Semiconductor Field Effect Transistor
MSL  Multilayer Soft Lithography
mVLSI  microfluidic Very Large-Scale Integration
MVVM  Model-View-ViewModel
NMO  N-type Metal Oxide Semiconductor
NW  Naive Washing
PCR  Polymerase Chain Reaction
PDMS  Poly DiMethyl Siloxane
PLA  Programmable Logic Array
PLY  Python Lex-Yacc
PMOS  P-type Metal Oxide Semiconductor
RAM  Random Access Memory
RCL  Restrictive Candidate List
RNA  Ribose Nucleic Acid
SA  Simulated Annealing
SB  Synthetic Benchmark
TL  Tabu List
TS  Tabu Search
UML  Unified Modeling Language
USA  United States of America
μTAS  Miniaturized Total Analysis Systems
VLSI  Very Large-Scale Integration
WGA  Whole Genome Amplification
WPF  Windows Presentation Foundation
XML  eXtensible Markup Language
Notations

\( A(N, D) \) \hspace{1em} \text{Biochip architecture graph model, where} \ N \text{ is the set of vertices and} \ D \text{ is the set of edges}

\( a_i \) \hspace{1em} \text{Reachable mixing ratio}

\( B \) \hspace{1em} \text{Binding function for operations on components}

\( C \) \hspace{1em} \text{Set of execution times of a component}

\( C(U_C, V_C, E_C) \) \hspace{1em} \text{A connection bipartite graph model for a biochip architecture} \ A; \ U_C \text{ is the set of entry points,} \ V_C \text{ is the set of exit points and} \ E_C \text{ is the set of connections between them}

\( CF \) \hspace{1em} \text{Finite set of channel faults}

\( CF(N, t) \) \hspace{1em} \text{Channel fault on component} \ N \text{, of type} \ t

\( C_i \) \hspace{1em} \text{Execution time of operation} \ O_i

\( C_{M_j} \) \hspace{1em} \text{Execution time of} \ O_i \text{ on component} \ M_j

\( c(D_{ij}) \) \hspace{1em} \text{Routing latency of directed edge} \ D_{ij} \text{ in the architecture graph}

\( c(F_i) \) \hspace{1em} \text{Fluid routing latency along flow path} \ F_i

\( c_{\text{max}} \) \hspace{1em} \text{Maximum number of channel faults that can occur in} \ A, \text{ during fabrication}

\( CF(D_{ij}, t) \) \hspace{1em} \text{Channel fault on edge} \ D_{ij}, \text{ of type} \ t

\( \text{Cost}_A \) \hspace{1em} \text{Cost of architecture} \ A

\( \text{Cost}_{C(G)} \) \hspace{1em} \text{Approximated cost function for the grid graph} \ G_G

\( C_R \) \hspace{1em} \text{The set of routing grid cells, which are occupied by one of more routes}

\( C_{R(E)} \) \hspace{1em} \text{The set of cells which are occupied by routes in} \ R(E)

\( C'_{R(E)} \) \hspace{1em} \text{The set of cells which are occupied by routes in} \ R'(E)

\( D \) \hspace{1em} \text{Finite set of directed edges in} \ A

\( \text{depth} \) \hspace{1em} \text{Depth in the mixing tree}

\( d_0 \) \hspace{1em} \text{Deadline of the biochemical application graph} \ G

\( D_{ij} \) \hspace{1em} \text{Directed edge in} \ D \text{ from vertex} \ N_i \text{ to vertex} \ N_j

\( d(p) \) \hspace{1em} \text{A detour in the routing grid path} \ p

\( E \) \hspace{1em} \text{The subset of edges that change from the current solution} \ G_G \text{ to the neighbor solution} \ G'_G
\( \mathcal{E} \) Finite set of edges in \( \mathcal{G} \)
\( e_{i,j} \) Directed edge in \( \mathcal{E} \) from \( O_i \) to \( O_j \)
\( e_{u,v} \) An edge in \( \mathcal{C} \) that represents a connection from exit point \( u \), to entry point \( v \)
\( \mathcal{T} \) Finite set of flow paths in \( \mathcal{A} \)
\( F_i \) A flow path in \( \mathcal{T} \)
\( F_{i-j} \) A flow path between two vertices \( N_i \) and \( N_j \) in \( \mathcal{N} \)
\( F_{i}^{\text{ON}} \) Set of all Boolean input combinations, for which \( i \)th output evaluates to 1
\( F_{i}^{\text{OFF}} \) Set of all Boolean input combinations, for which \( i \)th output evaluates to 0
\( F_{i}^{\text{DC}} \) Set of all Boolean input combinations, for which \( i \)th output evaluates to “don’t care” (X)
\( \mathcal{FS} \) Set of all possible fault scenarios in \( \mathcal{A} \), under fault model \( \mathcal{J} \)
\( f \) A fault scenario
\( f(X) \) Boolean function for on-chip control
\( f_i \) \( i \)th input fluid in the fluid mixture
\( fI(f) \) Boolean variable that evaluates the connectivity of the architecture, under a fault scenario \( f \)
\( \mathcal{G} \) Biochemical application graph model
\( G_G(V_G, E_G) \) Grid graph, where \( V_G \) is the set of cells in the routing grid, and \( E_G \) is the set of edges defining adjacent cells
\( G_C(V_C, E_C) \) Coloring graph for pin-count minimization, where \( V_C \) are the vertices and \( E_C \) are the edges
\( H \) Geometric dimensions of a component
\( H(G_G) \) The neighborhood solutions of grid graph \( G_G \)
\( \text{Heater}_i \) Heater component in the biochip architecture
\( I_A(e_{uv}, e_{pq}) \) Intersection function between routes \( e_{uv} \) and \( e_{pq} \)
\( I(e) \) List of edges that intersect \( e \)
\( I_R(c_i, c_j) \) Set of intersection cells between adjacent routing grid cells, \( c_i \) and \( c_j \)
\( \text{Ini}_i \) Input port (reservoir) in the biochip architecture
\( \mathcal{J} \) Fault model
\( \mathcal{K} \) Finite set of routing constraints for \( \mathcal{A} \)
\( K_i \) One of the routing constraints in \( \mathcal{K} \), which is a finite set of flow paths that are mutually exclusive with the flow path \( F_i \in \mathcal{T} \)
\( \mathcal{L} \) Component model library
\( L(m) \) Set of all vertices of the subject tree corresponding to leaves of pattern trees for \( m \in \mathcal{M}(v) \)
\( L_A \) The approximated total length of the routes, found as the sum of the Manhattan lengths of all edges
\( L_M \) Squared two-dimensional Manhattan distance
\( L_R \) Total length of all routes in \( \mathcal{C} \)
\( L_R(E) \) The total length of routes in \( R(E) \)
\( L_R(E) \) The total length of routes in \( R'(E) \)
\( \mathcal{M} \) Finite set of components in an architecture
\( M_l \) One of the components in \( \mathcal{M} \)
\( M(v_i,v_j) \) Manhattan distance between \( v_i \) and \( v_j \) in the routing grid
\( M(v) \) Set of all matching pattern trees in the Tree Covering Algorithm
\( \text{Mixer}_l \) Mixer component in the biochip architecture
\( \text{Met}_i \) Metering component in the biochip architecture
\( \mathcal{N} \) Finite set of vertices in \( A \)
\( \mathcal{N}(E) \) Number of intersections for edges \( E \) in solution \( G'_G \)
\( \mathcal{N}'(E) \) Number of intersections for edges \( E \) in solution \( G'_G \)
\( N_A \) Total number of intersections of channels
\( N_i \) One of the vertices in \( \mathcal{N} \)
\( N_R \) Total number of flow channel intersections
\( N_R(E) \) The number of intersections that are removed when routes \( R(E) \) are removed from \( G'_G \)
\( N'_R(E) \) The number of intersections that are introduced when the routes in \( R'(E) \) are added to \( G'_G \)
\( \emptyset \) Finite set of vertices in \( \mathcal{G} \)
\( O_l \) Operation in the application, one of the vertices in \( \emptyset \)
\( O_E(c) \) Overlap contribution for cell, \( c \), in \( C_{R(E)} \)
\( \text{Out}_i \) Output port in the biochip architecture
\( p \) A path in the routing grid
\( \mathcal{P} \) Set of operational phases of a component
\( P_R^2 \) Smallest power of two, greater than \( R \)
\( R \) Total sum of desired mixing fluid ratios
\( r(e) \) Set of cells for the route corresponding to connection \( e \)
\( R(E) \) The set of routes corresponding to edges in \( E \) for solution \( G'_G \)
\( \text{Res}_i \) A reservoir in the biochip architecture
\( R'(E) \) The set of routes corresponding to edges in \( E \) for solution \( G'_G \)
\( r_i \) Mixing ratios specified in the biochemical application
\( \mathcal{R}_f \) Flow channel routing
\( \mathcal{R}_c \) Control channel routing
\( \mathcal{R}_E \) Resource constraints for the allocation task
\( RL \) Ready list of operations for scheduling
\( \mathcal{S} \) Finite set of switches in the biochip architecture \( A \)
\( S_A \) The approximated total squared route length, found as the sum of the squares of the Manhattan lengths of all edges
\( S_i \) One of the switches in \( \mathcal{S} \)
\( S_R \) Total squared length of all routes in \( \mathcal{G} \)
\( \text{Storage}_i \) Storage component in the biochip architecture
\( t \) Type of fault
Temperature a parameter in the Simulated Annealing Algorithm; $T_0$ is the initial temperature and $T_{termination}$ is the termination temperature

$T(V_T, E_T)$ Subject tree used in the Tree Covering Algorithm

$t_{start}$ Start time of operation $O_i$

$t_{finish}$ Finish time of operation $O_i$

$Q_i$ Biochip control input signals used as input for the on-chip control circuits

$u$ Pattern graph for the Tree Matching Algorithm

$\mathcal{U}$ Allocation of architectural components

$v$ Subject graph for the Tree Matching Algorithm

$v_i$ A vertex in graph $G_G$ that represents cell $c_i$ in the routing grid

$V_i$ Function mapping integer variables in the Aqua code to integer values

$V_f$ Function mapping fluid variables in the Aqua code to operations in the application graph $G$

$\mathcal{V}_F$ Finite set of valve faults

$VF(N, w, t)$ Valve fault $w$ in component $N$, of type $t$

$v_{max}$ Maximum number of valve faults that can occur in $A$, during fabrication

$V_R$ The total overlap of flow channel intersection

$V'_R(E)$ Amount of overlap introduced from solution $G_G$ to $G'_G$

$w_i$ Waste outlet in the biochip architecture

$X$ Scheduling and fluid routing information

$Y$ One-dimensional Boolean space

$\mathcal{Z}$ Biochip architecture layer model for placement and routing

$\mathcal{Z}_F$ Biochip architecture fault model

$Z_i$ Control signal Boolean value for valves, which is an output of an on-chip biochip control circuit

$Z_f$ Placement of components in the flow layer

$Z_c$ Placement of valves in the control layer

$Z(c)$ Set of all occupants of a routing grid cell $c$

$Z_R(c)$ Set of routes at routing grid cell $c$

$Z_{e \in R(E)}(c)$ The set of routes at cell $c$ that are in $R(E)$

$\alpha(T)$ The temperature reduction function in the Simulated Annealing Algorithm

$\delta(f)$ Application completion time under a fault scenario $f$

$\delta_G$ Completion time of application $G$

$\Delta$ Cost increase from previous solution to current solution, $s$ the initial solution is denoted with $s_0$

$\Psi$ Implementation model

$\Delta V_R$ Change in overlap among flow channels in the architecture
Notations

$\eta$ Control logic (valve actuation sequence)
$\phi$ Mapping of the application (binding and scheduling) onto $A$
$\theta_i$ Set of available components for $O_i$
$\rho_i$ Rounding error for mixing
$\sigma_E$ Cumulative rounding error in fluid ratios for mixing
$\sigma_R$ Sum of rounding fluid ratios for mixing