Design Automation Renegades

Globetrotting Division

Boilerplate Code: Data Structures and Algorithms for Design Automation

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Report on
Common Data Structures and Algorithms
Found in Bolierplate Code for
Design Automation Software

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Abstract

This report describes the design and implementation of common data structures and algorithms, as well as "computational engines" that are found in electronic design automation (EDA) software.

Data structures and algorithms for digital VLSI and cyber-physical system design include: binary decision diagrams (BDDs), AND-inverter graphs (AIGs), and their associated algorithms for optimization, traversal, and other operations (such as graph matching). Common computational engines for digital systems would include: optimization and verification engines for deterministic and nondeterministic finite state machines; decision procedures for the boolean satisfiability problem (SAT solvers) and satisfiability modulo theories (SMT solvers); quantified boolean formula (QBF) solvers; and SAT and SMT solvers for maximum satisfiability (i.e., Max-SAT and Max-SMT solvers).

Regarding EDA problems that require numerical computation (in digital, analog, or mixed-signal VLSI design), the data structures and algorithms for circuit simulation based on sparse graph would be required. In addition, techniques for model order reduction shall be implemented.

Computational engines for statistical and probabilistic analyses or stochastic modeling can include data structures and algorithms for partially observable Markov decision processes (POMDPs) and Markov chains. Tools for analyses of queueing systems (based on queueing theory) should be included.

Regarding cyber-physical systems and mixed-signal circuits, hybrid automata can be used to represent these circuits and systems.

Optimization engines for EDA include: solvers for different types of mathematical programming, such as linear programming (LP), integer linear programming (ILP), mixed-integer linear programming (MILP), quadratic programming (QP), convex programming (CP), geometric programming (GP), and second-order conic programming (SOCP); solvers for pseudo-boolean optimization (PBO solvers) and weighted-boolean optimization (WBO); and meta-heuristics (e.g., evolutionary algorithms, simulated annealing, and ant colony optimization).

Algorithms shall be implemented using parallel programming, in a scalable style. In addition, considerations shall be given to the use of constraint programming.

More stuff to be included...

Revision History

Revision History:

1. Version 0.1, December 23, 2014. Initial copy of the report.
2. Version 0.1.1, September 16, 2015. Added sections for mathematics and statistics, and the abstract.

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Chapter 1

Algorithms

This section documents algorithms that I have implemented for my C++ -based boilerplate code repository.

A template for typesetting algorithms is shown in PROCEDURE 1.

```
NAME OF THE ALGORITHM(ARGUMENTS)
       // Input ARGUMENT #1: Definition1
       // Input ARGUMENT #2: Definition2
 1     BODY OF THE PROCEDURE
       // A while loop.
 2     while [condition]
 3         [Something]
       // A for loop.
 4     for $Var$ = [initial value] to [final value]
 5         [Something]
       // An if-elseif-else block.
 6     if [Condition1]
 7         Blah...
 8     elseif [Condition2]
 9         Blah...
10     elseif [Condition3]
11         Blah...
12     else
13         Blah...
       // A variable assignment.
14     $blah = A[j]$
           // This is indented with a tab.
       // What is the output of this procedure?
15     return
```

Chapter 2

Data Structures

2.1 Graphs

2.1.1 Directed Graphs

2.1.1.1 Functions that need to be implemented

2.1.1.2 Binary Decision Diagrams (BDDs)

2.1.1.3 AND-Inverter Graphs (AIGs)

2.1.2 Undirected Graphs

Chapter 3

Mathematics

Math symbols that I use frequently:

1. $\mathbb{N}$
2. $\sum\limits_{n}^{i=1}$
3. $f(x) = \lim\limits_{n \to \infty} \dfrac{f(x)}{g(x)}$
4. $\varnothing$
5. q

A 3×3 matrix: $\begin{pmatrix} 11 & 12 & 13 \\ 21 & 22 & 23 \\ 31 & 32 & 33 \end{pmatrix}$

Here is an equation:

$$\iint_{\Sigma} \nabla \times \mathbf{F} \cdot \mathrm{d}\boldsymbol{\Sigma} = \oint_{\partial\Sigma} \mathbf{F} \cdot \mathrm{d}\mathbf{r}. \tag{3.1}$$

Here is an equation that is not numbered.

$$\nabla \times \mathbf{E} = -\frac{\partial \mathbf{B}}{\partial t}$$

Here is the set of Maxwell's equations that is numbered.

$$\nabla \cdot \mathbf{E} = \frac{\rho}{\varepsilon_0} \tag{3.2}$$

$$\nabla \cdot \mathbf{B} = 0 \tag{3.3}$$

$$\nabla \times \mathbf{E} = -\frac{\partial \mathbf{B}}{\partial t} \tag{3.4}$$

$$\nabla \times \mathbf{B} = \mu_0 \left(\mathbf{J} + \varepsilon_0 \frac{\partial \mathbf{E}}{\partial t} \right) \tag{3.5}$$

$$\begin{gathered}\text{minimize} \sum_{\mathrm{i}=1}^{\mathrm{c}} \mathrm{c_i} \cdot \mathrm{x_i} \\ \underline{x} \in S \\ \text{subject to}: \\ x_1 + x_4 = 0 \\ x_3 + 7 \cdot x_4 + 2 \cdot x_9 = 0\end{gathered}$$

$$f(n) = \begin{cases} case - 1 & : \text{n is odd} \\ case - 2 & : \text{n is even} \end{cases} \tag{3.6}$$

Proof. This is a proof for BLAH ... □

Theorem 3.1. *TITLE of theorem. My theorem is...*

Axiom 3.1. *TITLE of axiom. Blah...*

Cases of putting a bracket/parenthesis on the right side of the equation.

$$\left.\begin{aligned} B' &= -\partial \times E, \\ E' &= \partial \times B - 4\pi j, \end{aligned}\right\} \quad \text{Maxwell's equations}$$

Labeling an arrow: $\xrightarrow{ewq}$

Chapter 4

Statistics

Chapter 5

C++ Resources

Some C++ and C++ STL resources are:

1. [26]: http://www.tutorialspoint.com/cplusplus/cpp_stl_tutorial.htm
2. [8] and CplusplusCom2015: http://www.cplusplus.com/reference/stl/
3. http://en.cppreference.com/w/cpp/container
4. http://www.cs.wustl.edu/~schmidt/PDF/stl4.pdf
5. Pointers to functions: http://www.cplusplus.com/doc/tutorial/pointers/

C++ topics:

1. Function objects:
   (a) https://en.wikipedia.org/wiki/Functional_(C%2B%2B)
   (b) http://stackoverflow.com/questions/356950/c-functors-and-their-uses
   (c) http://www.cprogramming.com/tutorial/functors-function-objects-in-c++.html
2. Strings:
   (a) [47], Chp 23
   (b) [46], Chp 23
   (c) [14], Chp 18
   (d) [3], Chp 19
   (e) [10], Chp 1
3. IO Streams:
   (a) [10], Chp 2
   (b) [11], Chp 12. See all of [11–13].
   (c) [47], Chp 10-11
   (d) [46], Chp 10-11
   (e) [29], Chp 16
   (f) [49], Chp 10
   (g) [44], Chp 21
   (h) [3], Chp 28
   (i) [14], Chp 12
   (j) [34], Chp 17
   (k) [24], Chp 8
4. Templates:
   (a) [10], Chp 3
   (b) [9], Chp 16

   (c) [47], Chp 19
   (d) [46], Chp 19
   (e) [29], Chp 24
   (f) [49], Chp 6
   (g) [2], book; typelist - Chp 3
   (h) [44], Chp 18
   (i) [48], book
   (j) [1], book
   (k) [3], Chp 29
   (l) [14], Chp 11,21
   (m) [24], Chp 16

5. Debugging:
   (a) [10], Chp 11 (especially memory management problems, pp. 533)

6. STL containers:
   (a) [10], Chp 4
   (b) [45], Chp 8
   (c) [29], Chp 25
   (d) [49], Chp 7
   (e) [35], book
   (f) [3], Chp 18
   (g) [14], Chp 15-16
   (h) [34], Chp 16
   (i) [24], Chp 9,11

7. STL algorithms:
   (a) [10], Chp 5
   (b) [29], Chp 25
   (c) [49], Chp 7
   (d) [35], book
   (e) [3], Chp 18
   (f) [14], Chp 15,17
   (g) [34], Chp 16
   (h) [24], Chp 10

8. Function addresses:
   (a) [9], Chp 3, pp. 213
   (b) [47], Chp 8
   (c) [46], Chp 8

9. Dynamic memory management problems:
   (a) [9], Chp 6,13
   (b) [11], Chp 13. See all of [11–13].
   (c) [25], Chp 2-4
   (d) [44], Chp 29
   (e) [3], Chp 14
   (f) [14], Chp 10,22
   (g) [34], Chp 9,12
   (h) [24], Chp 12,13

10. Function overloading:
    (a) [9], Chp 7
    (b) [11], Chp 6. See all of [11–13].
    (c) [47], Chp 8
    (d) [46], Chp 8
    (e) [44], Chp 14
11. Operator overloading:
    (a) [9], Chp 12
    (b) [29], Chp 18
    (c) [44], Chp 15
    (d) [24], Chp 14
12. Constants:
    (a) [9], Chp 8
13. Functions and pointers:
    (a) [9], Chp 11:
        i. use const at the end of accessor functions
        ii. Do not use pointers as instance variables
    (b) [47], Chp 8:
        i. Pass-by-reference: e.g., void init(vector<double> &v)
        ii. Pass-by-const-reference: e.g., void print(const vector<double> &v)
        iii. Pass-by-value: e.g., void fn(int x)
    (c) [46], Chp 8
    (d) [29], Chp 15,20
    (e) [3], Chp 12-13
    (f) [34], Chp 7-8
    (g) [24], Chp 6
    (h) Elsewhere:
        i. You cannot call a non-const method from a const method. That would 'discard' the const qualifier.:
            A. `http://stackoverflow.com/questions/2382834/discards-qualifiers-error`
        ii. Pointer to constant data: *const type* variable;* and *type const * variable;*
            A. `http://www.cprogramming.com/reference/pointers/const_pointers.html`
        iii. Pointer with constant memory address: *type * const variable = some-memory-address;*
            A. `http://www.cprogramming.com/reference/pointers/const_pointers.html`
        iv. Constant data with a constant pointer: *const type * const variable = some-memory-address;* and *type const * const variable = some-memory-address;*
            A. `http://www.cprogramming.com/reference/pointers/const_pointers.html`
        v. `http://stackoverflow.com/questions/1143262/what-is-the-difference-between-const-`
        [27]:
            A. Read it backwards; the first *const* can be on either side of the type.
            B. "Read pointer declarations right-to-left."
            C. From the answer of Ted Dennison, July 17, 2009. **Rule: The "const" goes after the thing it applies to. Putting const at the very front (e.g., const int *) is an exception to the rule.**
            D. int* – pointer to int
            E. int const * == const int * – pointer to const int
            F. int * const – const pointer to int

G. int const * const == const int * const – const pointer to const int
H. int ** – pointer to pointer to int
I. int ** const – A const pointer to a pointer to an int
J. int * const * – A pointer to a const pointer to an int
K. int const ** – A pointer to a pointer to a const int
L. int * const * const – A const pointer to a const pointer to an int

vi. For the following [27], let: *int var0 = 0;*
    A. *const int &ptr1 = var0;* // Constant reference
    B. *int * const ptr2 = &var0;* // Constant pointer
    C. *int const * ptr3 = &var0;* // Pointer to const
    D. *const int * const ptr4 = &var0;* // Const pointer to a const

14. OOD and inheritance:
    (a) [9], Chp 14,15
    (b) [11], Chp 13,14,15. See all of [11–13].
    (c) [47], Chp 9
    (d) [46], Chp 9
    (e) [29], Chp 13-14,21
    (f) [49], Chp 3-4,8
    (g) [3], Chp 24-26
    (h) [14], Chp 4-9
    (i) [34], Chp 10-11,13,14,15
    (j) [24], Chp 7,15,18,19
15. SW engineering issues:
    (a) [3], Chp 21
    (b) [14], Chp 24-26
16. multi-threading:
    (a) [45], Chp 3
17. graphs:
    (a) [45], Chp 7

Books to classify:

1. C++ programming: [17, 22, 23, 32, 33, 38, 39, 41–43]
2. C++ STL: [5–7, 15, 16, 19, 20, 36, 37]
3. C++ -based MPI programming: [21]
4. scientific computing: [30]
5. Boost C++: [28, 31, 40]

5.1 Computational Complexity of C++ Containers

Table 5.1 shows a tabulated summary of containers in the *C++* Standard Template Library (STL) and the computational complexity for each of their common operations: add(element e), remove(element e), search(element e), size(), empty(), begin(), and end().

To conclude, we can get some facts about each data structure:

1. `std::list` is very very slow to iterate through the collection due to its very poor spatial locality.
2. `std::vector` and `std::deque` perform always faster than `std::list` with very small data

Table 5.1: Computational Complexity of Basic Operations of Containers from the *C++ STL*.

Container \ Complexity	add	remove	search	size	empty	begin	end
vector	O(1)	O(n)	O(n)	O(1)	O(1)	O(1)	O(1)
list	O(1)	O(n)	O(n)	O(1)	O(1)	O(1)	O(1)
queue	O(1) amortized	O(1)	O(n)	O(1)	O(1)	O(1)	O(1)
priority queue	O(log n)	O(log n)	O(n)	O(1)	O(1)	O(1)	???
set	O(log n)	O(log n)	O(log n)	O(1)	O(1)	O(1)	O(1)
multi-set	O(log n)	???	O(log n)	O(1)	O(1)	O(1)	O(1)
map	O(log n)	O(log n)	O(log n)	O(1)	O(1)	O(1)	O(1)
multi-map	O(log n)	???	O(log n)	O(1)	O(1)	O(1)	O(1)
stack	O(1)	O(1)	O(n)	O(1)	O(1)	O(1)	O(1)

3. `std::list` handles very well large elements
4. `std::deque` performs better than a `std::vector` for inserting at random positions (especially at the front, which is constant time)
5. `std::deque` and `std::vector` do not support very well data types with high cost of copy/assignment

This draw simple conclusions on usage of each data structure [4, 18]:

1. Number crunching: use std::vector or std::deque
2. Linear search: use std::vector or std::deque
3. Random Insert/Remove:
4. Small data size: use std::vector
5. Large element size: use std::list (unless if intended principally for searching)
6. Non-trivial data type: use std::list unless you need the container especially for searching. But for multiple modifications of the container, it will be very slow.
7. Push to front: use std::deque or std::list

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