Arrays in C++

November 15, 2010

What's an Array?

1d Array A location in memory with space for multiple variables of the same type.

Array Element One of the variables in an array.

What's an Array?

1d Array A location in memory with space for multiple variables of the same type.

Array Element One of the variables in an array.

- How are they declared?
- How are they initialized?
- How are specific elements accessed and modified?

Allocate Space for Arrays

These allocate space for the arrays, but do not specify element values.

Space for 3 integers, named `intArray`:

```
int intArray[3];
```

Space for 5 doubles, named `dblArray`:

```
const int DBLARRAY(5);
double dblArray[DBLARRAY];
```

Allocate Array Space by Initialization

These allocate space implicitely by specifying the value of each array element.

Space for 3 integers, named `intArray`, with specific values:

```
int intArray[] = { 12, 0, 2 };
```

Space for 5 double values, named `dblArray`:

```
double dblArray[] = { 12, 0, 2.3, -5, 6 };
```

Error: arrays are not associative in C++

```
double array[] = { 1, 1.0, "3.14"};
```

Allocate Array Space by Size and Value

These allocate arrays of specific sizes, with values for initial elements.
All remaining elements are initialized to 0 (zero).

Space for 3 integers, named `intArray`, with specific values:

```
int intArray[3] = { 12, 0, 2 };
```

Space for 5 `double` values, named `dblArray`, with some initial values:

```
double dblArray[5] = { 12, 0, 2.3 };
```

Space for `LENGTH` `bools`, named `truthSequence`, all initialized to `false`*:

```
const int LENGTH = 1024;
bool truthSequence[LENGTH] = { };
```

*Technically, I'm not convinced the last form is allowed by the C++ Language Specification, but practially all compilers allow this form.

Array Declaration Rule

Error: size and initial value list must agree

```
double oops[3] = { 4.5, 3.2, 2.1, 3.14 };
```

Error: at least one of size or initial values must be provided

```
int ugh[] = {}; // NO INITIAL VALUES!
```

Array Declaration Rule

Error: size and initial value list must agree

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double oops[3] = { 4.5, 3.2, 2.1, 3.14 };
```

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```
int ugh[] = {}; // NO INITIAL VALUES!
```

Array sizes must be specified at array declaration — explicitely or implicitly.

Try question 1.

Array Memory

```
1 const int SIZE(5);
2 double array[SIZE] = { 2.3, -5.1, 6 };
```

Array Values:	2.3	-5.1	6	0	0	?
Element Number:	1	2	3	4	5	DNE
Element Offset:	0	1	2	3	4	5

Array Memory

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What is special about the red 0s?

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Why DNE?

Array Memory

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Why DNE? What does the question mark mean?

Array Memory

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What is special about the red 0s?

Why DNE? What does the question mark mean?

Which row of this table represents a segment of computer memory?

Array Memory

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What is special about the red 0s?

Why DNE? What does the question mark mean?

Which row of this table represents a segment of computer memory?

Why is Element Offset blue?

Manipulating (Partially Filled) Array Elements

```
1  /***
2   * Read in at most 8 percentiles from cin and print
3   * them back out converted to fractional equivalents.
4   */
5  #include <iostream>
6  using namespace std;
7
8  int main()
9  {
10     const int MAXPOINTS( 8 );
11     double percents[MAXPOINTS];  // values will be read from cin
12
13     // prompt and read
14     cout << "Enter␣percents␣at␣the␣keyboard␣(with␣percent␣sign);" << endl;
15     cout << "Maximum␣" << MAXPOINTS << "␣points,␣or␣'end'␣to␣stop:␣" << endl;
16
17     // read, count with p
18     int p = 0;
19     while( p < MAXPOINTS ) {
20         char percent_sign;
21         if( !( cin >> percents[p] >> percent_sign )) {
22             // read failure
23             break;
24         }
```

Run Edit

Answer question 5.

Beware...

- Array indices must be integral variables (`bool, char, int`).
- Arrays do not have a `( )`-style initialization syntax, so
  Arrays cannot be initialized with
  ```
  double array[]( {1.0,2,3} );          //will not compile
  ```
- An array can not be printed to the console or disk file with a simple cout statement:

  ```
  cout << intArray << endl;
  ```

  a `for` loop must be used to iterate and print each element individually.
- Arrays can not have multiple element values set with one assignment operation.
  ```
  int intArray[3];
  intArray = { 10, 11, 12 };          //will not compile
  ```

What's a 2d-Array?

2d Array An array of arrays!

- We need at least two sets of `{}` to specify non-trivial initialization values,
- We need two sets of `[]` for declaration and element access, ...
- ...we treat these two `[]`-operators as the ROW and COLUMN specifier for the array.

Think of a 2d C++ array as a matrix in mathematics.

$$\texttt{array[ROWS][COLS]} \sim \texttt{array[3][4]} \sim \begin{bmatrix} 1 & 2 & 3 & 4 \\ -2 & 1 & 2 & 1 \\ -3 & -2 & 1 & 0 \end{bmatrix}$$

2d Array Example

```
1  /***
2   * Read in at most an N x N integer array and determine if
3   * it is symmetrical or not.
4   */
5  #include <iostream>
6  #include <cstdlib> // exit
7  using namespace std;
8
9  int main()
10 {
11     const int N( 8 );
12     int A[N][N];  // Matrix of max size NxN
13     int n; // user specified matrix size
14
15     // prompt and read
16     cout << "Enter the matrix dimension: " << flush;
17     if( !( ( cin >> n ) && n >= 1 && n <= N )) {
18         cout << "Error: n is invalid (" << n << ")" << endl;
19         // system("PAUSE"); // uncomment for windoze */
20         exit(1);
21     }
22     cout << "Enter the matrix (" << n << 'x' << n << "): " << flush;
23     for( int i(0); i<n; i++ ) {
24         for( int j(0); j<n; j++ ) {
```

Run Edit

Declaring 2d Arrays

Declare Space Only

```
2 // Declare space for arrays
3 int intArray[3][4];
4 const int ROWS(3), COLS(4);
5 double dblArray[ROWS][COLS];
```

$$\texttt{intArray[3][4]} = \begin{bmatrix} ? & ? & ? & ? \\ ? & ? & ? & ? \\ ? & ? & ? & ? \end{bmatrix}$$

$$\texttt{dblArray[3][4]} = \begin{bmatrix} ? & ? & ? & ? \\ ? & ? & ? & ? \\ ? & ? & ? & ? \end{bmatrix}$$

Declaring 2d Arrays

Declare & Initialize All Elements

```
9  // Declare and initialize all values
10 const int ROWS(3), COLS(4);
11 int intArray[ROWS][COLS] = {
12  {  1,  2,  3,  4 },
13  { -2,  1,  2,  3 },
14  { -3, -2,  1,  2 },  // lingering comma OK
15   };
16
17 // Note the extra comma is ok...
18 double dblArray[2][2] = {
19  {  1,  1.0, }, // extra internal comma OK
20  {  2,  2.0, },
21   };
22
23 // Note the missing first [ROWS] parameter!
24 double dblArray2[][3] = {
25  {  1,  2, 3 },
26  { -2,  1, 2 },
27  { -3, -2, 1 },
28   };
```

$$\texttt{intArray[3][4]} = \begin{bmatrix} 1 & 2 & 3 & 4 \\ -2 & 1 & 2 & 3 \\ -3 & -2 & 1 & 2 \end{bmatrix}$$

$$\texttt{dblArray[2][2]} = \begin{bmatrix} 1.0 & 1.0 \\ 2.0 & 2.0 \end{bmatrix}$$

$$\texttt{dblArray2[][3]} = \begin{bmatrix} 1.0 & 2.0 & 3.0 \\ -2.0 & 1.0 & 2.0 \\ -3.0 & -2.0 & 1.0 \end{bmatrix}$$

Declaring 2d Arrays

Declare & Use Default Zero Initialization

```
32 // Declare and initialize some values
33 double dblArray[5][3] = {
34  { 1, 2, 3 },
35  { 1, 2 },
36  { 0 },
37  {},
38  // MISSING 5th row (offset 4)
39   };
40
41 int intArray[5][3] = {};
```

$$\texttt{dblArray[5][3]} = \begin{bmatrix} 1.0 & 2.0 & 3.0 \\ 1.0 & 2.0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \end{bmatrix}$$

$$\texttt{intArray[5][3]} = \begin{bmatrix} 0 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \end{bmatrix}$$

Limits on Implicitely Declared Size

```
2     // 2 implicit dimensions
3     // DOES NOT WORK!
4     double dblArray[][] = {
5         {  1,  1.0, },
6         {  2,  2.0, },
7             };
8
9     // Implicit columns
10    // DOES NOT WORK!
11    int intArray[4][] = {
12        {  1,  2,  3,  4 },
13        { -2,  1,  2,  3 },
14        { -3, -2,  1,  2 },
15            };
16
17    // Only implicit rows WORKS
18    double dblArray2[][3] = {
19        {  1,  2, 3 },
20        { -2,  1, 2 },
21        { -3, -2, 1 },
22            };
```

Only the first dimension of any multidimensional array can be implicitely determined by the compiler!

```
4:  error: declaration of ‘dblArray’  must have bounds for all dimensions except the first
11:  error: declaration of ‘intArray’  must have bounds for all dimensions except the first
```

Try question 6 parts a–c, and f.

Binary Search

Suppose you have a sorted array of 12 numbers.

13	25	26	29	30	43	49	53	61	79	85	93

Is there an efficient way to determine if some other number, x is in the array?

Binary Search

Take $x = 54$ as an example.

We could start in the middle, noticing that $x > 43$

13	25	26	29	30	43	49	53	61	79	85	93

. . . then notice $x < 61$

13	25	26	29	30	43	49	53	61	79	85	93

. . . and now $x > 49$

13	25	26	29	30	43	49	53	61	79	85	93

. . . but $53 < x < 61$

13	25	26	29	30	43	49	53	61	79	85	93

$x = 54$ **is not** in the table, it **would have been** between 53 and 61.

13	25	26	29	30	43	49	53	61	79	85	93

Binary Search

Suppose a **haystack**: a sorted array of n numbers, and a **needle** (x in the previous example).

The binary search algorithm is the most efficient way to answer:

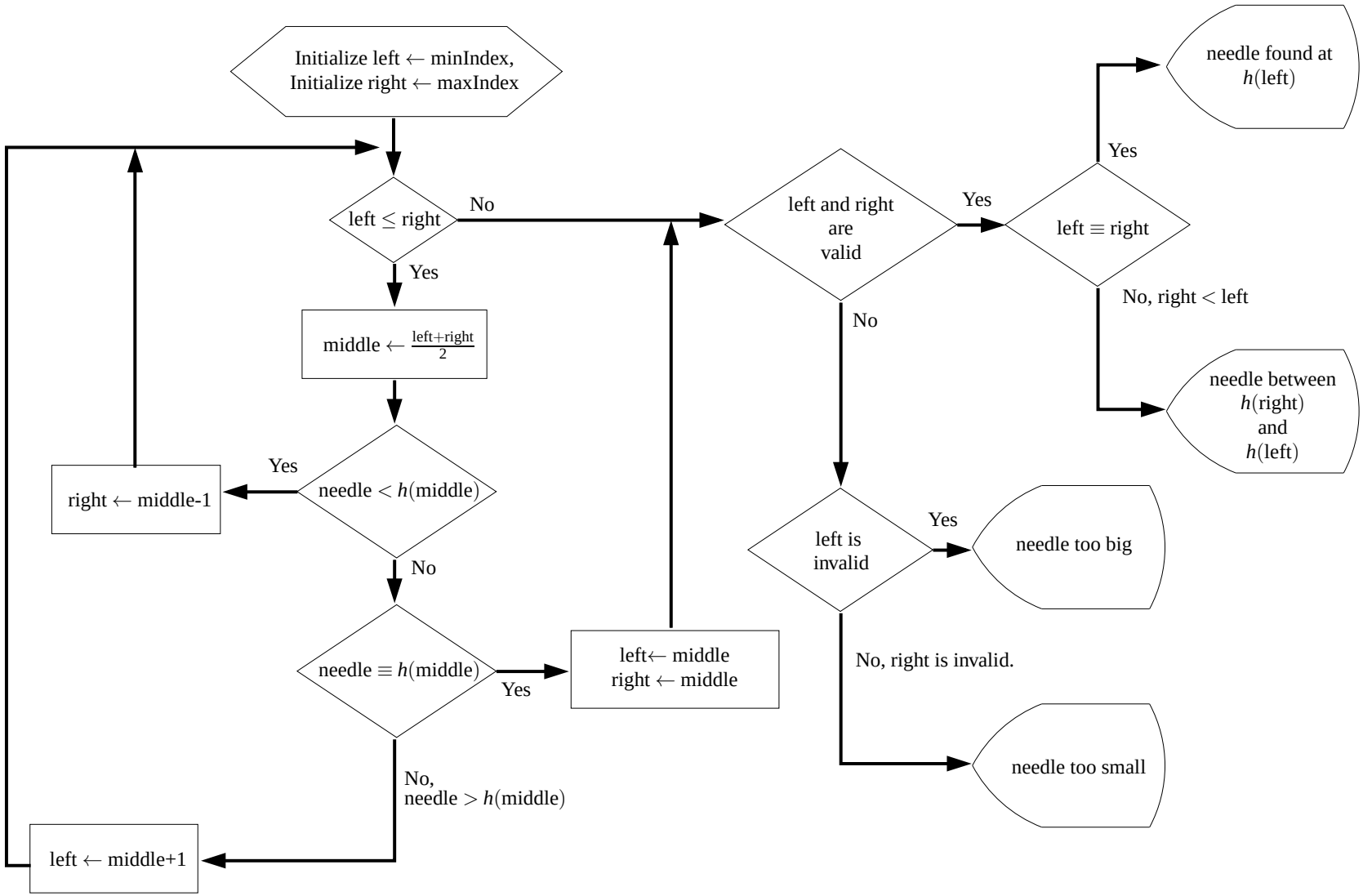
- is the needle in the haystack?
- is the needle too small for the haystack?
- is the needle too big for the haystack?
- or where it should be in the haystack?

Binary Search

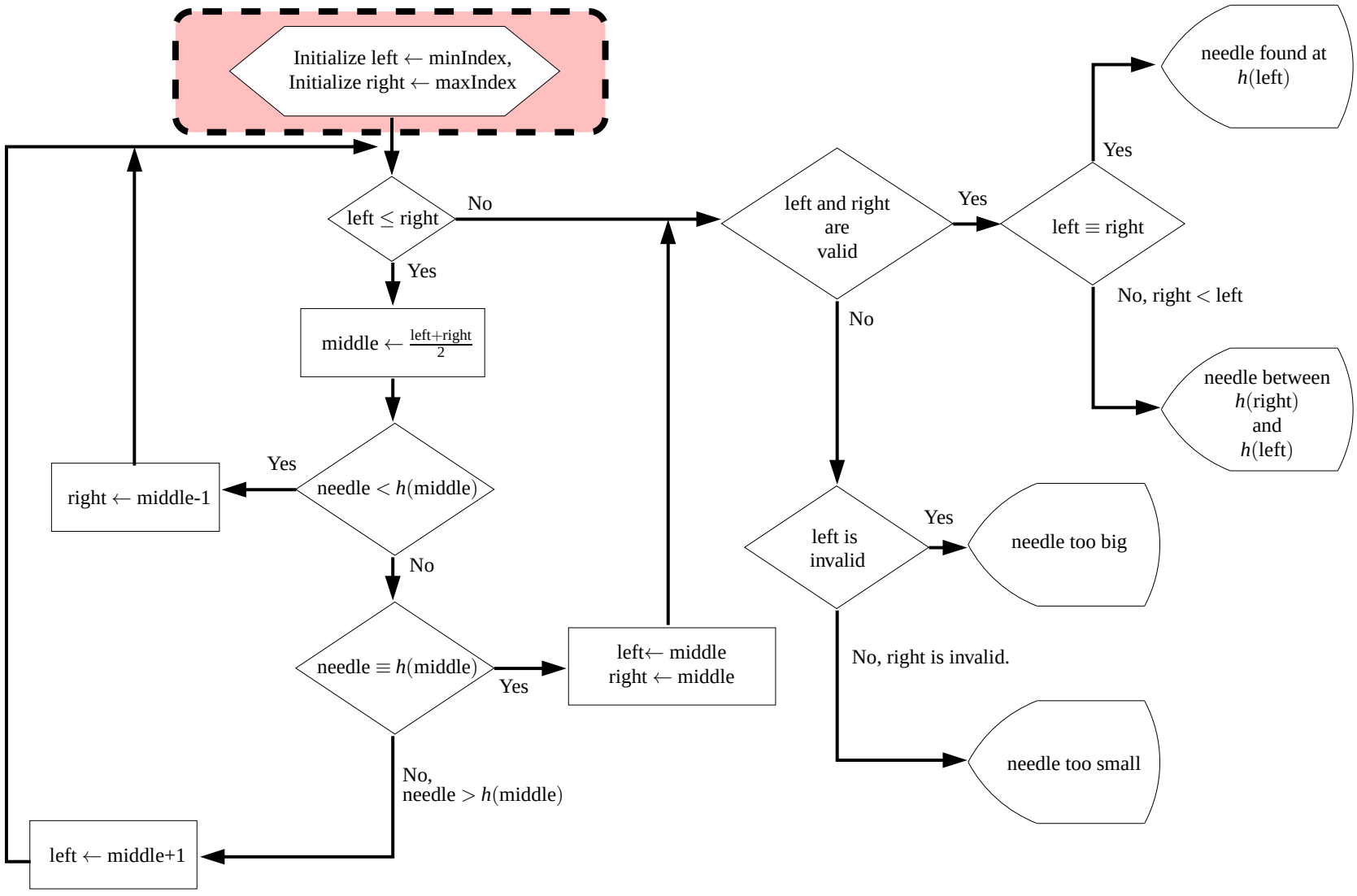
Suppose `needle=54; ...`

Loop	Variables			Haystack Element Indices											
	`left`	`right`	`middle`	0	1	2	3	4	5	6	7	8	9	10	11
1	0	11	$5 = \frac{0+11}{2}$	13	25	26	29	30	43	49	53	61	79	85	93
	`needle > haystack[middle]` ⇒ `left = middle + 1;`														
2	6	11	$8 = \frac{6+11}{2}$	13	25	26	29	30	43	49	53	61	79	85	93
	`needle < haystack[middle]` ⇒ `right = middle - 1;`														
3	6	7	$6 = \frac{6+7}{2}$	13	25	26	29	30	43	49	53	61	79	85	93
	`needle > haystack[middle]` ⇒ `left = middle + 1;`														
4	7	7	$7 = \frac{7+7}{2}$	13	25	26	29	30	43	49	53	61	79	85	93
	`needle > haystack[middle]` ⇒ `left = middle + 1;`														
	8	7		13	25	26	29	30	43	49	53	61	79	85	93

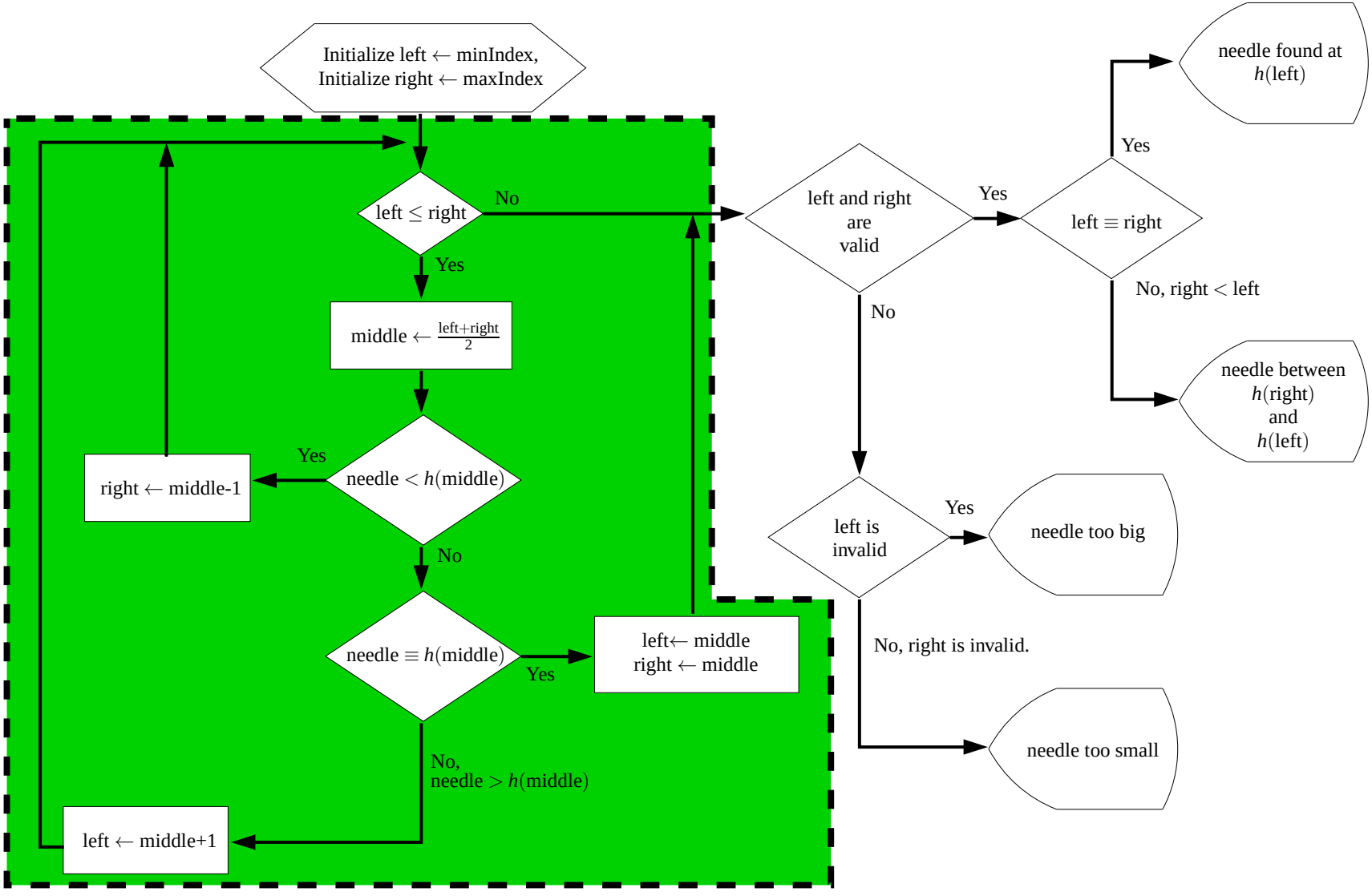
Binary Search



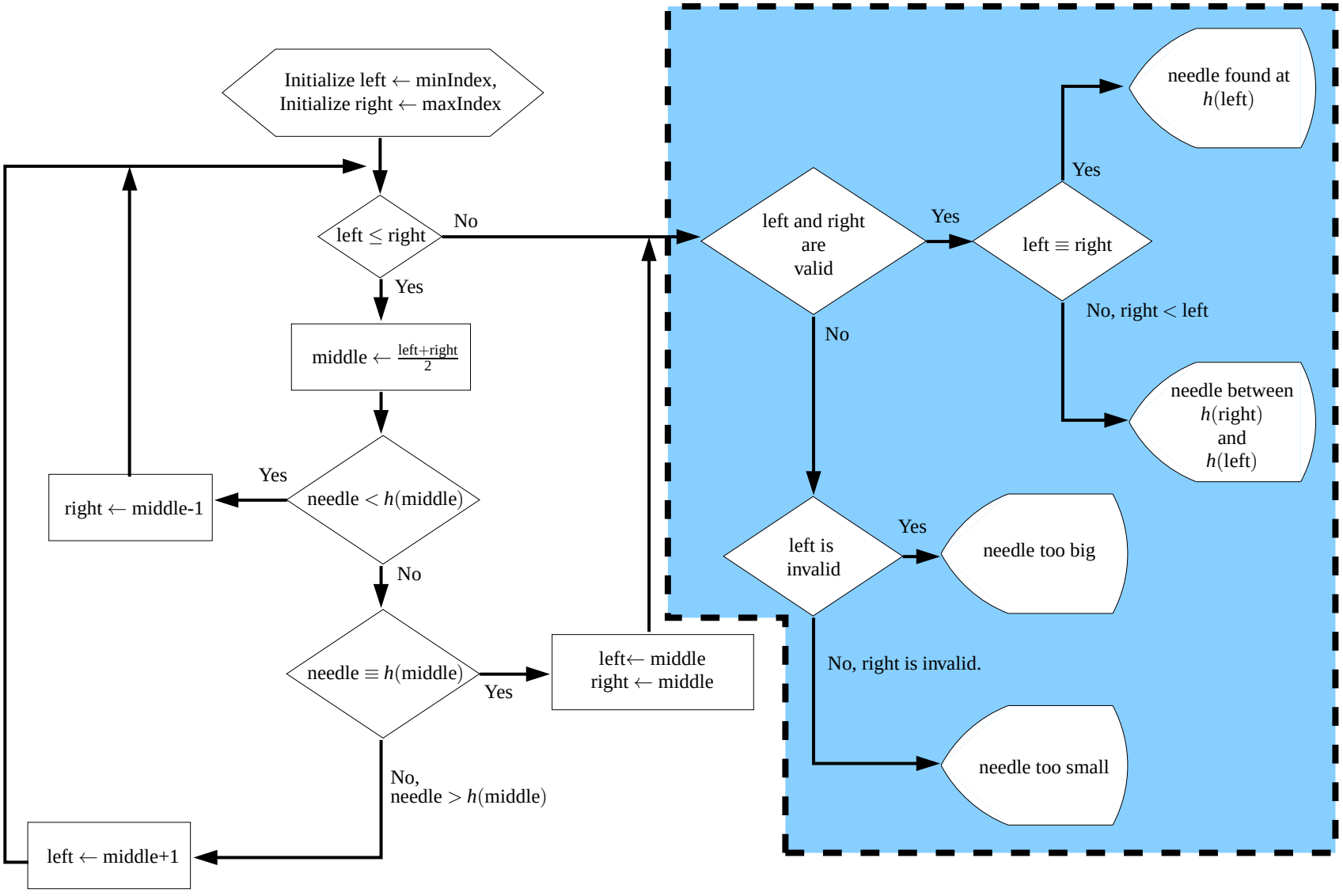
Binary Search — Initialize Variables



Binary Search — `while()` Loop Search



Binary Search — Interpret Results



Binary Search — Practice!

Suppose `needle=10; ...`

Loop	Variables			Haystack Element Indices											
	`left`	`right`	`middle`	0	1	2	3	4	5	6	7	8	9	10	11
1	?	?	?	13	25	26	29	30	43	49	53	61	79	85	93
	`needle ???  haystack[middle]` ⇒ `???`														

Binary Search — Practice!

Suppose `needle=10; ...`

Loop	Variables			Haystack Element Indices											
	`left`	`right`	`middle`	0	1	2	3	4	5	6	7	8	9	10	11
1	0	11	$5 = \frac{0+11}{2}$	13	25	26	29	30	43	49	53	61	79	85	93
	`needle < haystack[middle]` ⇒ `right = middle - 1;`														
2	0	4	$2 = \frac{0+4}{2}$	13	25	26	29	30	43	49	53	61	79	85	93
	`needle < haystack[middle]` ⇒ `right = middle - 1;`														
3	0	1	$0 = \frac{0+1}{2}$	13	25	26	29	30	43	49	53	61	79	85	93
	`needle < haystack[middle]` ⇒ `right = middle - 1;`														
	0	-1		13	25	26	29	30	43	49	53	61	79	85	93

Magical C++ Strings

```
1  /***
2   * This application demonstrates the C++ string api
3   */
4
5  #include <cstdlib>
6  #include <iostream>
7  #include <string>
8  using namespace std;
9
10 int main( )
11 {
12     const string theString( "Ramblin' wreck from Golden Tech," );
13
14     // string objects support a member function length() and array (like)
15     // access to char values!
16     for( int i(0); i<theString.length(); /* empty */ ) {
17         cout << i << ":" << theString[i] << "\t";
18         if( !(++i%5) ) cout << endl;
19     }
20     cout << endl;
21
22     // the member function find(...) returns the index of a searched for string,
23     // or -1 if the string cannot be found.
24     cout << "wreck is at index " << theString.find( "wreck" ) << endl;
```

Run Edit

Cycling Through Arrays

Use % to keep index or offset arithmetic
within the bounds of array dimensions.

Modulus is usually faster and more memory efficient than `if` statements.

Try question 7

Serialized Element Offsets in 2d Arrays

If the elements of an `M`×`N` $2d$ array are valued in (western) page-reading order beginning with $0 \ldots$

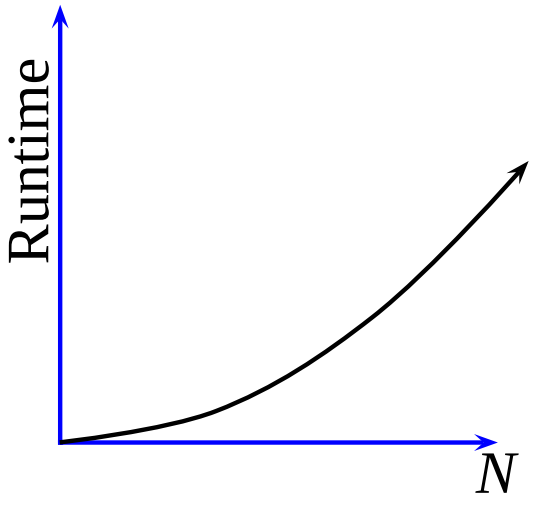
$$\begin{bmatrix} 0 & 1 & \ldots & N-1 \\ N & N+1 & \ldots & \ldots \\ \ldots & \ldots & MN-2 & MN-1 \end{bmatrix}$$

$\ldots$ the row index of an element with value `x` is `x/N`,

$\ldots$ the column index of an element with value `x` is `x%N`.

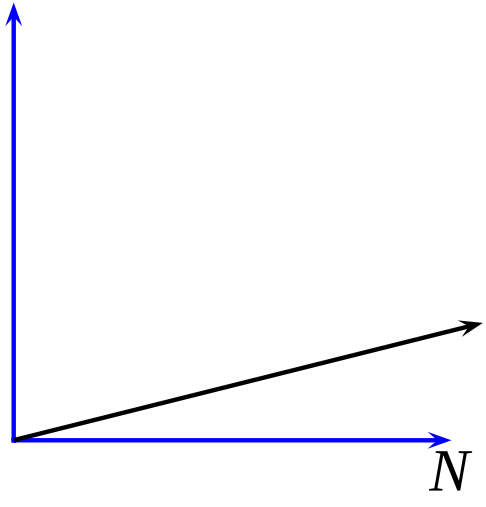
Big-Θ (Big-O) & Asymptotic Runtimes

Quadratic Time



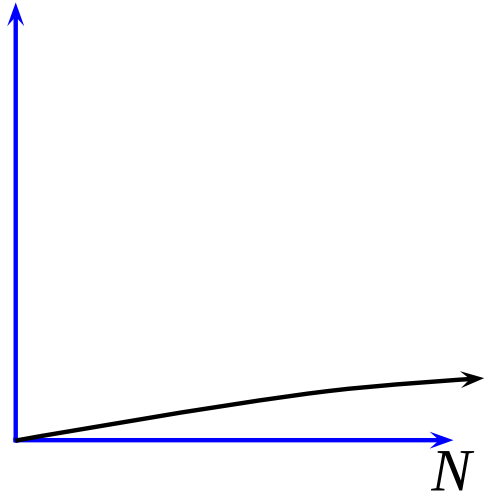

```
// Quadratic Time
for(int i=2; i<N; i++){
  for(int j=2; j<=sqrt(i); j++){
    // Work done in j-loop
    // proportional to the
    // value of i
  }
}
```

Linear Time




```
// Linear time
for(int i=0; i<N; i++){
  // A constant amount of
  // work for i=0, i=1,
  // ... i=N-2, i=N-1
}
```

Log Time




```
// Log time
left = 0; right = N-1;
while( left <= right ) {
  middle = (left+right)/2;
  // Each iteration of
  // the loop reduces
  // the "size" of the
  // problem by 1/2.
}
```

Data Centric Programming

> *"Show me your flowcharts and conceal your tables, and I shall continue to be mystified. Show me your tables, and I won't usually need your flowcharts; they'll be obvious."*
>
> *— Fred Brooks in The Mythical Man-Month*

Data centric programming puts the emphasis on the **data**, and less so on the **logic**. Some problems are difficult or impossible to approach from the vantage point of data centric programming.

When data centric programming can be used, it requires insight and a fair amount of thought. The reward is an application that is short, sweet, and to the point. The results can be surprising.

Paper-Rock-Scissors without `if/if-else` Statements

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