Unit 2c – Arrays

Mark Redekopp

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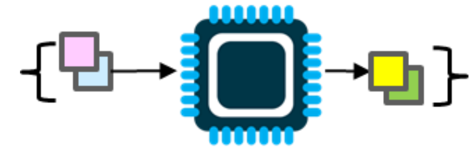
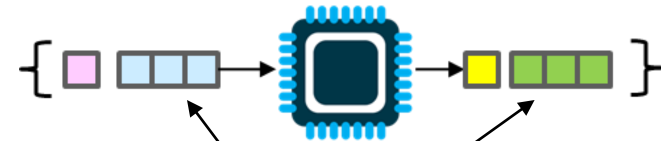
Unit 2

- **Unit 1**: Scalar processing
  - aka IPO=Input-Process-Output Programs

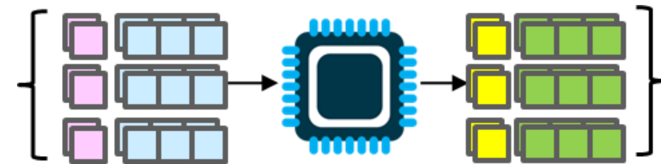


- **Unit 2**: Linear (1D) Processing

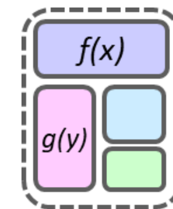


How do we store these data sets

- **Unit 3**: Multidimensional Processing



- **Unit 4**: Divide & Conquer (Functional Decomposition)



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Motivating Example

- Suppose I need to store the grades for all students so I can then compute statistics, sort them, print them, etc.
- I would need to store them in variables that I could access and use
  - This is easy if I have 3 or 4 students
  - This is painful if I have many students

```
int main()
{
  int score1, score2, score3;
  cin >> score1 >> score2 >> score3;

  // output scores in sorted order
  if(score1 < score2 &&
     score1 < score3)
  {  /* score 1 is smallest */ }

  /* more */
}
```

```
int main()
{
  int score1,  score2,  score3,
      score4,  score5,  score6,
      score7,  score8,  score9,
      score10, score11, score12,
      score13, score14, score15,
      /* ... */
      score139, score140;
  cin >> score1 >> score2 >> score3
      >> score4 >> score5 >> score6
      /* ... */
```

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Control vs. Data Structures

- Language constructs that allow us to make decisions are referred to as **control structures**
  - The common ones are: if statements, while loops, for loops
- We also need ways to store our data so we can access it easily and efficiently
- Arrays are the simplest data structure and the only one that C/C++ supports natively
  - Other data structures are available through other library code (but arrays need no additional code included)

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Array Basics

- An array are a named collection of ordered variables of the same type that are accessed with an index and stored contiguously in memory
  - **Named collection:** One name to refer to the collection of variables
  - **Ordered:** There is a first and a last and one comes before another
  - Accessed with an **index**: Each variable is accessed with its position/index (using [] brackets)
  - **Same Type**: Variables in one array must all be the same type (one array can't store doubles and ints)

```
int main()
{
  int scores[140];
    // allocates 140 integers
    //  with garbage values


  for(int i=0; i < 140; i++){
    cin >> scores[i];
  }
}
```

Addr: Index:	520 [0]	524 [1]	528 [2]		1076 [139]
scores:	96	84	93	...	90

Computer Memory

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Accessing An Element

- Once an array is declared, there is nothing "special" about it. Each variable must be initialized and accessed 1 at a time.
- To access an individual variable/element of an array of size *n*, use the name of the array followed by square brackets containing ANY expression (constant, variable, arithmetic) that will evaluate to an index from ***0 to n-1***
  - ***Note: Indexing starts at 0***

```
int main()
{
  int x = 1, myval = 5;
  int scores[10];
    // allocates 10 integers

  scores[4] = 73;

  scores[x] = 82;
    // sets scores[1]

  scores[2*x + 1] = 93;
    // sets scores[3]

  scores[1+max(x,myval)] = 88;
    // sets scores[6]
}
```

Addr: Index:	520 [0]	524 [1]	528 [2]	532 [3]	536 [4]	540 [5]	544 [6]	
scores:	??	82	??	93	73	??	88	...

Computer Memory

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Loops and Arrays (1)

- The real power of arrays is found when you combine them with loops
- Use the loop control variable (`int i`) to serve as the index of the array entry to be modified or accessed
  - Whether the array has 1 or 1,000,000 elements, our code size does not grow

```
int main()
{
  int x = 1, myval = 5;
  int scores[100];
    // allocates 100 integers

  // initialize all to 0
  for(int i=0; i < 100; i++){
    scores[i] = 0;
  }

  // ..OR.. read in all entries
  for(int i=0; i < 100; i++){
    cin >> scores[i];
  }

}
```

Addr: Index:	520 [0]	524 [1]	528 [2]	532 [3]	536 [4]	540 [5]	540 [6]	
scores:	0	0	0	0	0	0	0	...

Computer Memory

Loops and Arrays (2)

- How could we determine the average score?

```
int main()
{
  int scores[100];
  /* ... fill in the data ... */

  // Average all values

  for(int i=0; i < 100; i++){


  }
  cout << _____________________ << endl;

  return 0;
}
```

Addr: Index:	520 [0]	524 [1]	528 [2]	532 [3]	536 [4]	
scores:	9	7	8	8	6	...

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Loops and Arrays (3)

- How could we determine the max score?

```
int main()
{
  int scores[100];
  /* ... fill in the data ... */

  // Find maximum


  for(int i=0; i < 100; i++){




  }
  cout << "Max: " << _____ << endl;
  return 0;
}
```

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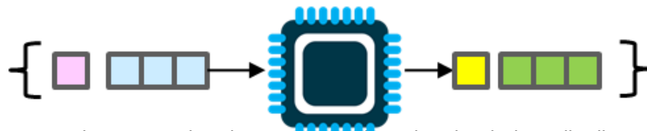
When Do We Need Arrays?

- Arrays ***can*** store many related data items of the same type
- A better question is when do we ***need*** to store these related data items in an array?
- We need arrays when we need to **revisit the data more than once**
  - If we just want to find the min/max or average we could just get the data from the user and update the sum or min/max as we go and not need to store each data item
  - Don't introduce arrays where they are not needed



```
int main()
{
  int scores[100];
  // Get the data
  for(int i=0; i < 100; i++){
    cin >> scores[i];
  }
  // Average all values
  int sum = 0;
  for(int i=0; i < 100; i++){
    sum += scores[i];
  }
  cout << sum / 100.0 << endl;

  return 0;
}
```

```
int main()
{
  int val, sum = 0;
  // Get the data & average it
  // at the same time
  for(int i=0; i < 100; i++){
    cin >> val;
    sum += val;
  }
  cout << sum / 100.0 << endl;
  return 0;
}
```

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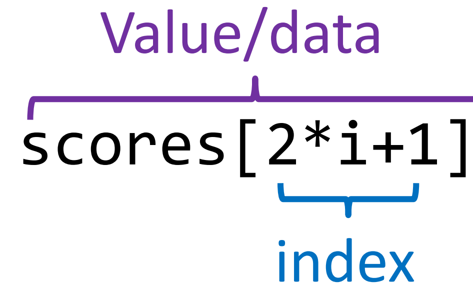
Index vs. Value

- The expression in the square brackets is an index
- Using *array[index]* yields the data/value in the array at that index
- An index can be **ANY EXPRESSION**, even the value from an array or the return value from a function
- For an array declared to be size **n**, only indices **0 to n-1** are legal



Addr:	520	524	528	532	536	
Index:	[0]	[1]	[2]	[3]	[4]	
scores: (values)	9	0	7	8	6	...

Computer Memory

```
int main()
{
  int scores[20];
  /* ... fill in the data ... */

  int i = 1;
  int x = scores[2*i + 1];       // x=_
  int y = scores[ scores[1] ]; // y=_
  int z = scores[max(4,2)];     // z=_
  return 0;
}
```

stribute

A Common Error

- Care must be taken to ensure no index is used that will lead to an out-of-bounds access
  - Such an access will either corrupt other data or cause the program to crash!
  - These are often known as **segmentation faults**. When you see one, your **first** thought should be to check for a **bad array index!**

Addr:	520	524	528	532	596	600
Index:	[0]	[1]	[2]	[3]	[19]	
scores: (values)	9	0	7	...	6	?

Computer Memory

```
int main()
{
  int scores[20];
  /* ... init in the data ... */
  int i;
  for(i=0; i <= 20; i++){  // wrong?
     scores[i] = 0;
  }

  cin >> i;
  // what could happen here..not safe
  scores[i] = 100;

  // safe
  if( i >= 0 && i < 20 ){
    scores[i] = 100;
  }
  return 0;
}
```

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Important C/C++ Rule: Array Size

- C/C++ needs to know the **SIZE of the array** when the program is **compiled**, not when it is **run**.
  - This implies the size of the array must be **ONE, FIXED (or constant) size** everytime the program is run
- For this course, we will just allocate a LARGE array of the maximum size potentially needed and then use only a portion of it as the program runs
  - Future courses will teach you how to deal with this correctly and not waste array space

```
int main()
{
  // GOOD!!
  int data[24];   // 24 known at
                  // compile time

  // BAD!!
  int n;
  cin >> n;
  int data[n];    // n not known at
                  // compile time
}
```

```
int main()
{
  int data[100]; // max needed
  int n;
  cin >> n;

  for(int i=0; i < n; i++)
  {
    cin >> data[i];
  }
}
```

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Exercises 1

- cpp/arrays/fibonacci
- cpp/arrays/sorted

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ARRAY DETAILS

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Character Arrays

- C-Strings are stored as character arrays
  - Each character consumes 1 element in the array
  - Ends with the null character (e.g. 0 decimal or '\0' ASCII)
- Can use cin and cout with a character array to get a string from the keyboard or output a string
  - cin and cout will loop over the array inputting or printing one character at a time

Addr: Index:	520 [0]	521 [1]	522 [2]	523 [3]	524 [4]	525 [5]	526 [6]
str1:	'C'	'S'	' '	'1'	'0'	'2'	'\0'

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```
int main()
{
  char str1[7] = "CS 102";
  /* Initializes the array to "CS 102"*/

  str1[5] = '3'; // now "CS 103"

  cout << str1 << endl;
                 // prints "CS 103"

  cin >> str1; // get a new string from
               // the user (suppose user
               // types "hello")
  cout << str1;
}
```

Program Output:

```
CS 103
hello
```

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Initializing Arrays With Constants

- Arrays can be initialized with **constants** when they are declared
- To do so, use an initialization list which is a comma separated list of constants in {...}
  - **Exception:** If ***fewer*** values are provided than the size of the array, remaining elements will be filled with **0s**
- If an initialization list is provided you need not specify the size in the square brackets (i.e. just use empty []) as the compiler can figure out what size the array must be by counting the initial values

```
int main()
{
  int data[5] = {9, 7, 8, 9, 5};

  double dec[4] = {0.25, 0.3};

  char str1[3] = {'C', 'S', '\0'};
  // For char arrays easier to use ""
  char str2[3] = "CS";
  // str2 initialization is same as str1
}
```

Index:	[0]	[1]	[2]	[3]	[4]
data:	9	7	9	9	5

dec:	0.25	0.3	0	0

str1:			

```
int main()
{
  int data[] = {9, 7, 8, 9, 5};
    // allocates array of size 5

  double dec[] = {0.25, 0.3, 0.18, 0.2};
    // allocates array of size 4

  char str2[] = "CS";
    // allocates array of size 3
}
```

Index:	[0]	[1]	[2]	[3]	[4]
data:	9	7	9	9	5

Specifying sizes is not necessary when using initial values list

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Exercises 2

- cpp/arrays/sumpairs
  - Given an array of size n (n is even), output the sum of the
    - first and last
    - 2nd and 2nd to last
    - 3rd and 3rd to last

Addr: Index:	520 [0]	524 [1]	528 [2]	532 [3]	536 [4]	540 [5]	
scores:	0	0	0	0	0	0	...

Computer Memory

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SOLUTIONS

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Loops and Arrays (2)

- How could we determine the average score?

```
int main()
{
  int scores[100];
  /* ... fill in the data ... */

  // Average all values
  int sum = 0;
  for(int i=0; i < 100; i++){
    sum += scores[i];
  }
  cout << (double)sum / 100 << endl;

  // Find maximum
  int max = 0;
  for(int i=0; i < 100; i++){
    if( scores[i] > max)
     max = scores[i]
  }
  cout << "Max: " << max << endl;
  return 0;
}
```

Addr: Index:	520 [0]	524 [1]	528 [2]	532 [3]	536 [4]	
scores:	9	7	8	8	6	...

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Loops and Arrays (3)

- How could we determine the max score?

```
int main()
{
  int scores[100];
  /* ... fill in the data ... */

  // Find maximum
  int max = -1;
  for(int i=0; i < 100; i++){
    if( scores[i] > max)
     max = scores[i]
  }
  cout << "Max: " << max << endl;
  return 0;
}
```

Addr: Index:	520 [0]	524 [1]	528 [2]	532 [3]	536 [4]	
scores:	9	7	8	8	6	...

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Index vs. Value

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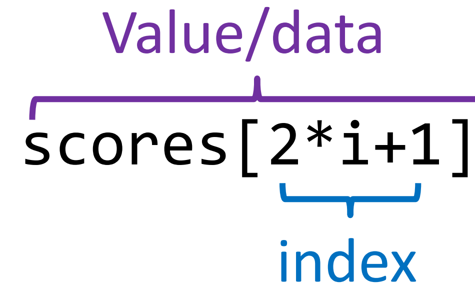


```
int main()
{
  int scores[20];
  /* ... fill in the data ... */

  int i = 1;
  int x = scores[2*i + 1];      // x=8
  int y = scores[ scores[1] ]; // y=9
  int z = scores[max(4,2)];    // z=6
  return 0;
}
```

Addr:	520	524	528	532	536	
Index:	[0]	[1]	[2]	[3]	[4]	
scores: (values)	9	0	7	8	6	...

Computer Memory

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