

CS1010

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Programming Methodology

UNIT 5

Top-Down Design & Functions



NUS
National University
of Singapore

School of
Computing

Unit 5: Top-Down Design & Functions

Objectives:

- How to analyse, design, and implement a program
- How to break a problem into sub-problems with step-wise refinement
- How to create your own user-defined functions

Reference:

- Chapter 3 Top-Down Design with Functions

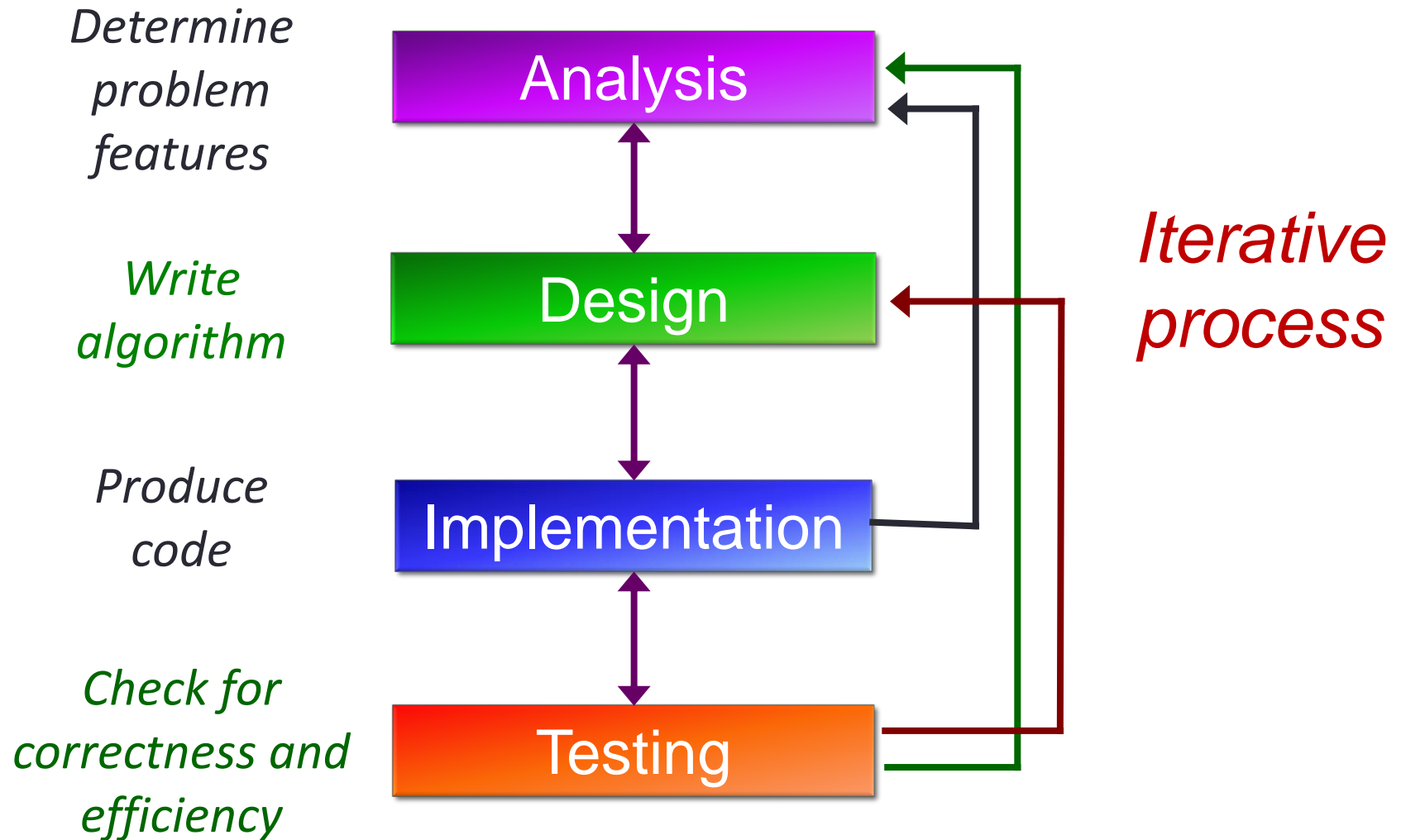
Unit 4: Top-Down Design & Functions (1/2)

1. Problem Solving
2. Case Study: Top-Down Design
 - Computing the weight of a batch of flat washers
 - Incremental Refinement (some hierarchical chart)
 - Top-down design (of program) with structure charts
3. Function Prototypes
4. Default Return Type
5. 'return' statement in main()

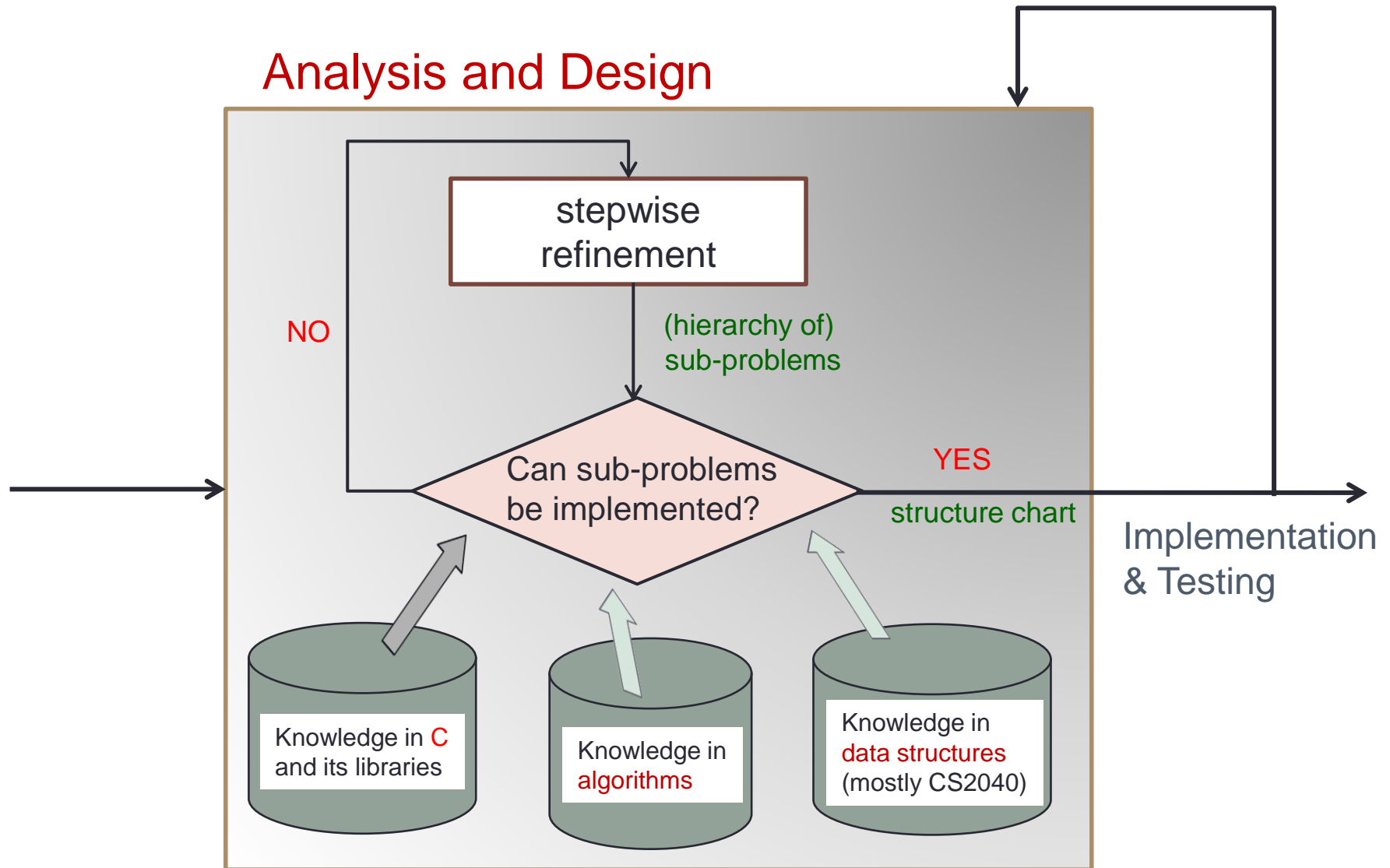
Unit 4: Top-Down Design & Functions (2/2)

- 6. Writing Functions
- 7. Exercise #1: A Simple “Drawing” Program
- 8. Pass-By-Value and Scope Rules
- 9. Global Variables

Problem Solving (1/2)




Problem Solving (2/2)



Top-Down Design (1/13)

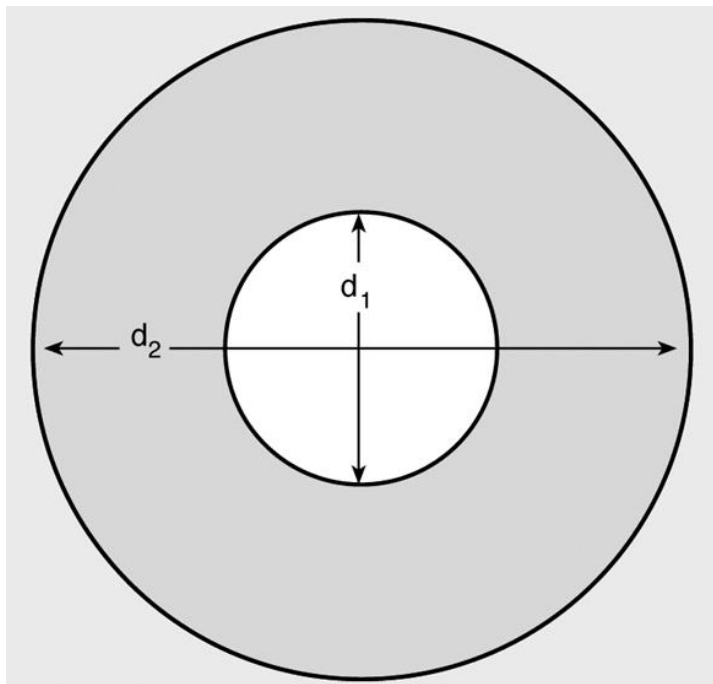
- We introduced some **math functions** in the previous unit.
- These math functions are provided in `<math.h>`.
- Such functions provide **code reusability**. Once the function is defined, we can use it whenever we need it, and as often as we need it.
- **Can we create our own functions?**
- In the following case study, we introduce **top-down design** in approaching an algorithm problem.
- In the process, we encounter certain tasks that are similar, hence necessitating the creation of **user-defined function**.



Decomposition!

Top-Down Design (2/13)

Case Study: You work for a hardware company that manufactures flat washers. To estimate shipping costs, your company needs a program that computes the weight of a specified quantity of flat washers.

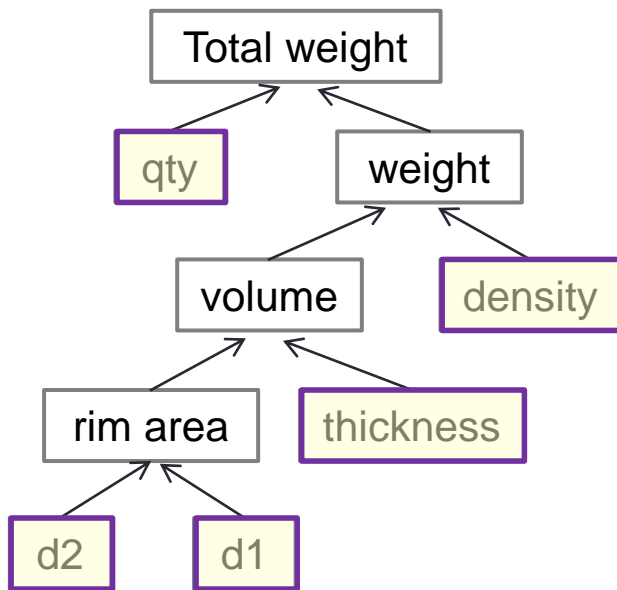


$$\text{rim area} = \pi(d_2/2)^2 - \pi(d_1/2)^2$$

Top-Down Design (3/13)

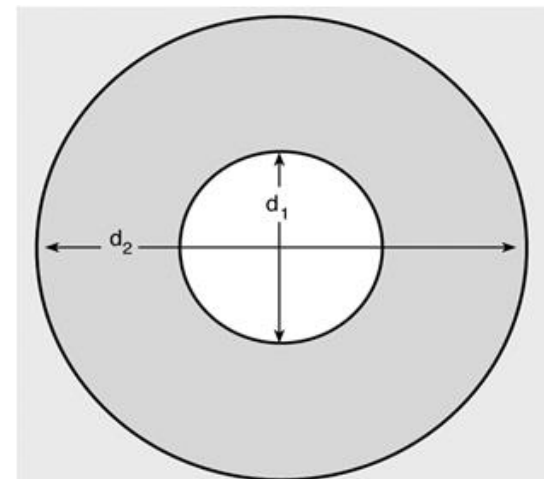
■ Analysis:

- To get the weight of a specified **qty** of washers, we need to know the **weight** of each washer
- To get the weight of a washer, we need its **volume** and **density** (weight = volume × density)
- To get the volume, we need its **rim area** and **thickness** (volume = rim area × thickness)
- To get the rim area, we need the diameters **d2** and **d1**



qty, density,
thickness, d2
and d1 are given
as inputs

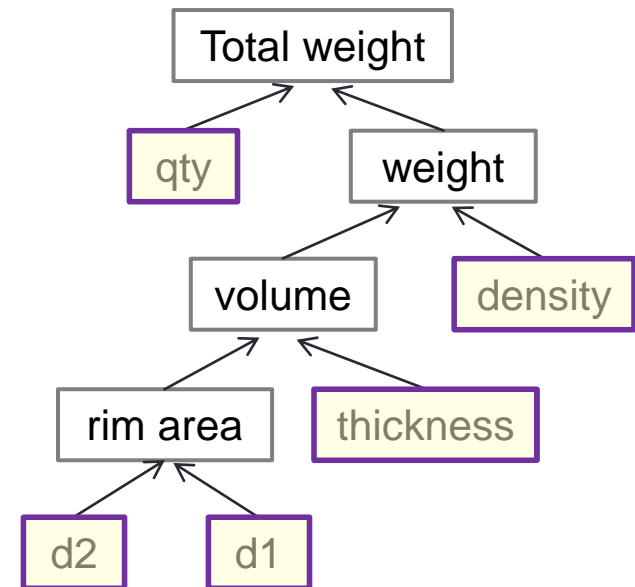
$$\text{rim area} = \pi(d_2/2)^2 - \pi(d_1/2)^2$$



Top-Down Design (4/13)

■ Design (pseudocode):

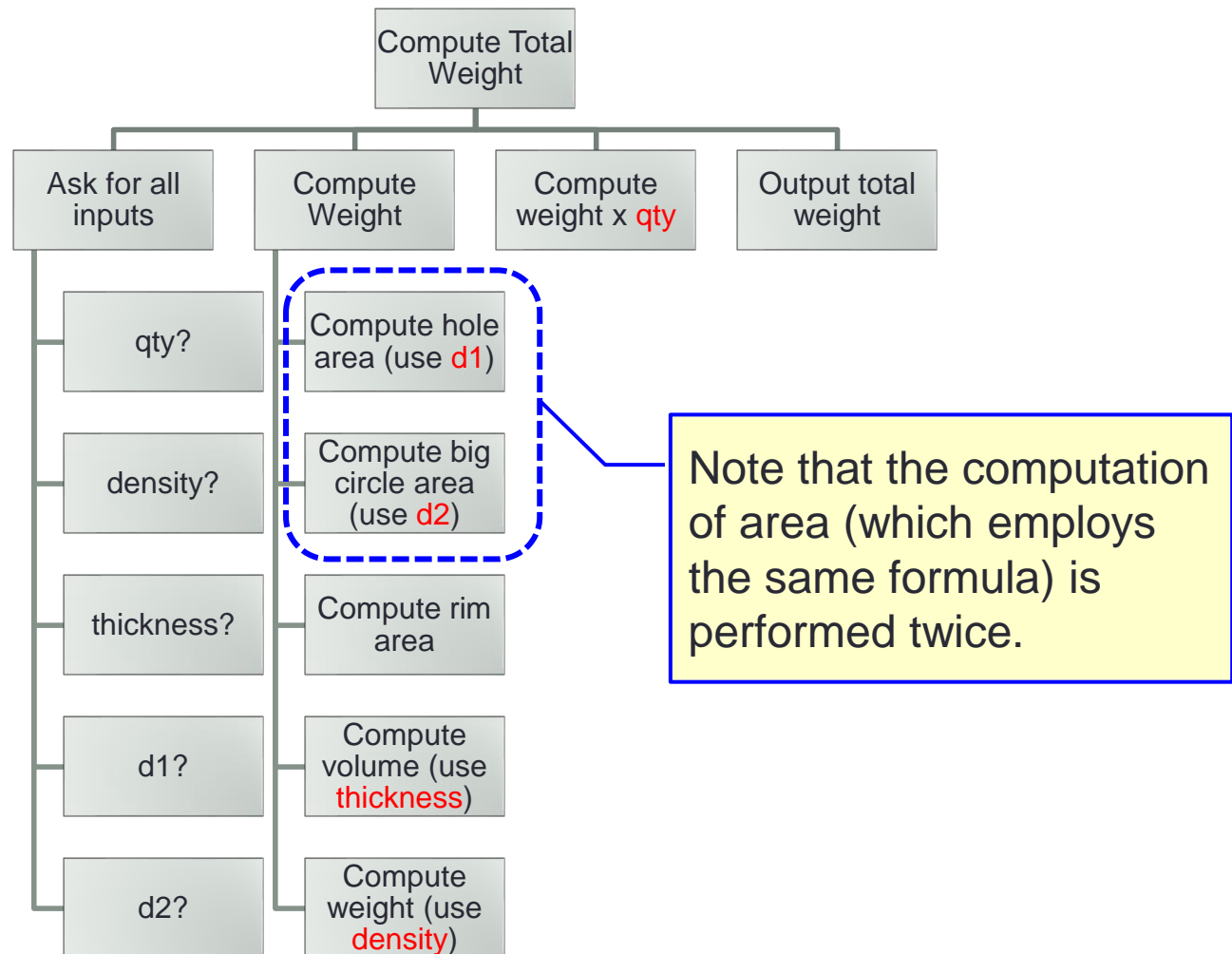
1. Read inputs (**qty**, **density**, **thickness**, **d2**, **d1**)
2. Compute weight of one washer
 - 2.1 Compute **area of small circle** (hole) using d1
 - 2.2 Compute **area of big circle** using d2
 - 2.3 Subtract small area from big area to get **rim area**
 - 2.4 Compute **volume** = rim area \times thickness
 - 2.5 Compute **weight** = volume \times density
3. Compute **total weight** of specified number of washer = weight \times qty
4. Output the calculated total weight



Step-wise refinement: Splitting a complex task (step 2) into subtasks (steps 2.1 – 2.5)

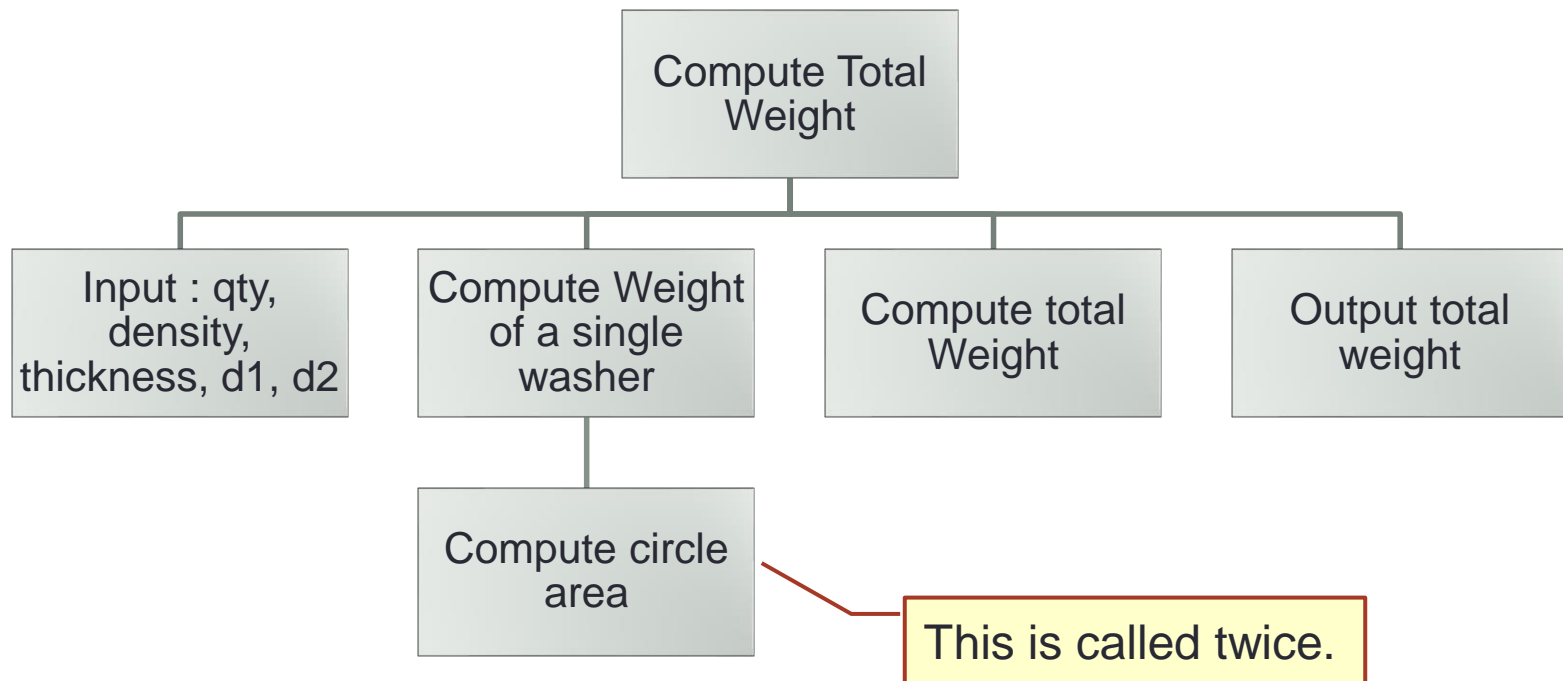
Top-Down Design (5/13)

- Design (hierarchical chart):



Top-Down Design (6/13)

- Design (structure chart):
 - A documentation tool that shows the **relationship** among the sub-tasks



Top-Down Design (7/13)

Unit5_Washers.c

```
#include <stdio.h>
#include <math.h>
#define PI 3.14159

int main(void) {
    double d1,           // hole circle diameter
           d2,           // big circle diameter
           thickness,
           density;

    int    qty;

    double unit_weight, // single washer's weight
           total_weight, // a batch of washers' total weight
           outer_area,   // area of big circle
           inner_area,   // area of small circle
           rim_area;     // single washer's rim area

    // read input data
    printf("Inner diameter in cm: "); scanf("%lf", &d1);
    printf("Outer diameter in cm: "); scanf("%lf", &d2);
    printf("Thickness in cm: "); scanf("%lf", &thickness);
    printf("Density in grams per cubic cm: "); scanf("%lf", &density);
    printf("Quantity: "); scanf("%d", &qty);
```


Top-Down Design (8/13)

Unit5_Washers.c

```
// compute weight of a single washer
outer_area = pow(d2/2, 2) * PI;
inner_area = pow(d1/2, 2) * PI;
rim_area = outer_area - inner_area;
unit_weight = rim_area * thickness * density;

// compute weight of a batch of washers
total_weight = unit_weight * qty;

// output
printf("Total weight of the batch of %d washers is %.2f grams.\n",
      qty, total_weight);

return 0;
}
```

gcc -Wall Unit5_washers.c -lm

Top-Down Design (9/13)

- Note that area of circle is computed twice. For code reusability, it is better to define a function to compute area of a circle.

```
double circle_area(double diameter) {  
    return pow(diameter/2, 2) * PI;  
}
```

- We can then call/invoke this function whenever we need it.

`circle_area(d2)` → to compute area of circle with diameter `d2`

`circle_area(d1)` → to compute area of circle with diameter `d1`

Top-Down Design (10/13)

```
#include <stdio.h>
#include <math.h>
#define PI 3.14159
```

```
double circle_area(double diameter) {
    return pow(diameter/2, 2) * PI;
}
```

Function
definition

```
int main(void) {
```

```
    // identical portion omitted for brevity
```

```
    // compute weight of a single washer
```

```
    rim_area = circle_area(d2) - circle_area(d1);
```

```
    unit_weight = rim_area * thickness * density;
```

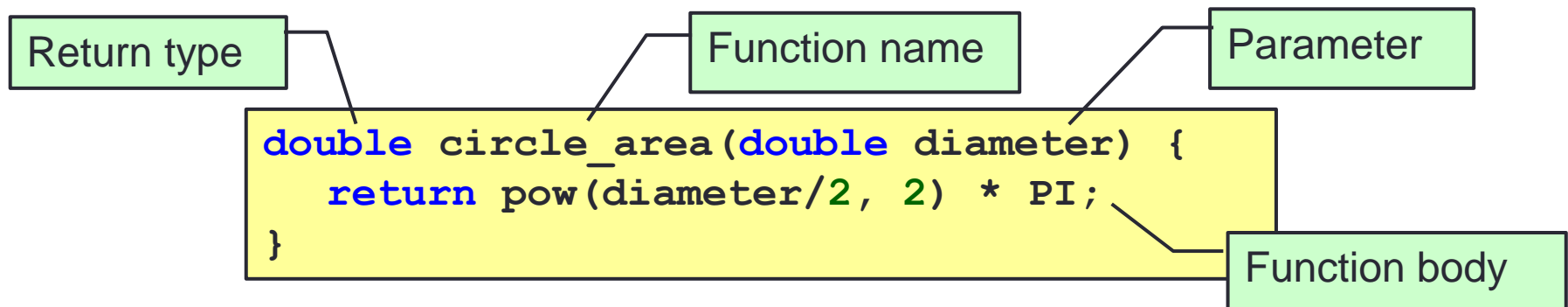
```
    // identical portion omitted for brevity
```

```
}
```

Calling `circle_area()`
twice.

Top-Down Design (11/13)

- Components of a **function definition**
 - Header (or signature): consists of **return type**, **function name**, and **a list of parameters** (with their types) separated by commas
 - Function names follow identifier rules (just like variable names)
 - May consist of letters, digit characters, or underscore, but cannot begin with a digit character
 - Return type is **void** if function does not need to return any value
 - Function body: code to perform the task; contains a **return** statement if return type is not void



Top-Down Design (12/13)

```
double circle_area(double diameter)
{
    return pow(diameter/2, 2) * PI;
}
```

- Values of arguments are copied into parameters

```
rim_area = circle_area(d2) - circle_area(d1);
```

Value of **d2** copied to
parameter **diameter**

Value of **d1** copied to
parameter **diameter**

- Arguments need not be variable names; they can be constant values or expressions

`circle_area(12.3)` → To compute area of circle with diameter 12.3

`circle_area((a+b)/2)` → To compute area of circle with diameter (a+b)/2, where a and b are variables

Top-Down Design (13/13)

- Preferred practice: add **function prototype**
 - Before main() function
 - Parameter names may be omitted, but not their type

Unit5_WashersV2.c

```
#include <stdio.h>
#include <math.h>
#define PI 3.14159
```

```
double circle_area(double);
```

Function prototype

```
int main(void) {
    // identical portion omitted for brevity

    // compute weight of a single washer
    rim_area = circle_area(d2) - circle_area(d1);
    unit_weight = rim_area * thickness * density;

    // identical portion omitted for brevity
}
```

Line 32 (see slide 21)

```
double circle_area(double diameter) {
    return pow(diameter/2, 2) * PI;
}
```

Line 45 (see slide 21)

Function definition

Function Prototypes (1/2)

- It is a good practice to put **function prototypes** at the top of the program, before the `main()` function, to inform the compiler of the functions that your program may use and their return types and parameter types.
- Function definitions to follow after the `main()` function.
- Without function prototypes, you will get error/warning messages from the compiler.

Function Prototypes (2/2)

- Let's remove (or comment off) the function prototype for `circle_area()` in `Unit5_WashersV2.c`
- Messages from compiler:

```
Unit5_WashersV2.c: In function 'main':  
Unit5_WashersV2.c:32:5: warning: implicit declaration of  
function 'circle_area'  
Unit5_WashersV2.c: At top level:  
Unit5_WashersV2.c:45:8: error: conflicting types for  
'circle-area'  
Unit5_WashersV2.c:32:16: previous implicit declaration of  
'circle_area' was here
```

- Without function prototype, compiler assumes the default (implicit) return type of `int` for `circle_area()` when the function is used in line 32, which conflicts with the function header of `circle_area()` when the compiler encounters the function definition later in line 45.

Default Return Type (1/3)

- A 'type-less' function has default return type of `int`

```
1 #include <stdio.h>
2
3 int main(void) {
4     printf("%d\n", f(100, 7));
5     return 0;
6 }
7
8 f(int a, int b) {
9     return a*b*b;
10 }
```

- Program can be compiled, but with warning:

```
warning: implicit declaration of function 'f' ← line 4
(due to absence of function prototype)
warning: return type defaults to 'int' ← line 8
```


Default Return Type (2/3)

- Another example

```
1 #include <stdio.h>
2
3 int main(void) {
4     f(100, 7);
5     return 0;
6 }
7
8 void f(int a, int b) {
9     return a*b*b;
10 }
```

Without function prototype, compiler assumes function **f** to be an **int** function when it encounters this.

However, **f** is defined as a void function here, so it conflicts with above.

- Program can be compiled, but with warning:

```
warning: implicit declaration of function 'f' ← line 4
(due to absence of function prototype)
warning: conflicting types for 'f' ← line 8
```


Default Return Type (3/3)

- **Tips**
 - Provide function prototypes for all functions
 - Explicitly specify the function return type for all functions

```
1 #include <stdio.h>
2
3 [int f(int, int);]
4
5 int main(void) {
6     printf("%d\n", f(100, 7));
7     return 0;
8 }
9
10 int f(int a, int b) {
11     return a*b*b;
12 }
```


'return' statement in main()

- Q: Why do we write `return 0;` in our `main()` function?
- Answer:
 - Our `main()` function has this header
`int main(void)`
 - Hence it must return an integer (to the operating system)
 - The value 0 is chosen to be returned to the operating system (which is UNIX in our case). This is called the `status code` of the program.
 - In UNIX, when a program terminates with a status code of 0, it means a successful run.
 - You may optionally check the status code to determine the appropriate follow-up action. In UNIX, this is done by typing `echo $?` immediately after you have run your program. – You do not need to worry about this.

Writing Functions (1/5)

- A **program** is a collection of functions (modules) to transform inputs to outputs
- In general, **each box** in a structure chart is a sub-problem which is handled by a **function**
- In mathematics, a **function** maps some input values to a **single** (possibly multiple dimensions) output
- In C, a **function** maps some input values to **zero or more** output values
 - **No output**: `void func(...) { ... }`
 - **One output**, e.g., `double func(...) { ...; return value; }`
 - **More outputs** through **changing input values** (we'll cover this later)
- **Return value** (if any) from function call can (but need not) be assigned to a variable.

Writing Functions (2/5)

Syntax:

```
function interface comment  
ftype fname (formal parameters list)  
{  
    local variable declarations  
    executable statements  
    return statement (if appropriate)  
}
```

Unit5_FunctionEg.c

```
/*  
 * Finds the square root of the  
 * sum of the squares of the two parameters  
 * Precond: x and y are non-negative numbers  
 */  
double sqrt_sum_square(double x, double y) {  
    // x and y above are the formal parameters  
  
    double sum_square; // local variable declaration  
  
    sum_square = pow(x,2) + pow(y,2);  
    return sqrt(sum_square);  
}
```

Notes:

Precondition: describes conditions that should be true **before calling** function.

Postcondition: describes conditions that should be true **after executing** function.

These are for documentation purpose.

Writing Functions (3/5)

Actual parameters (also **arguments**) are values passed to function for computation

Formal parameters (or simply **parameters**) are placeholder when function is defined.

- **Matching** of actual and formal parameters from left to right
- **Scope** of formal parameters, local variables are within the function only

```
// Function prototype at top of program
double sqrt_sum_square(double, double);

int main(void) {
    double y = 1.23; // not the same as y
                    // in sqrt_sum_square

    double z = 4.56;

    // x below not the same as x in sqrt_sum_square
    double x = sqrt_sum_square(y, z);

    printf("The square root of the sum of square ");
    printf("of %.2f and %.2f is %.2f\n", y, z, x);
    return 0;
}
```

```
double sqrt_sum_square(double x, double y)
{
    // x and y above are formal parameters

    double sum_square; // local variable

    sum_square = pow(x,2) + pow(y,2);

    return sqrt(sum_square);
}
```

- Arrows indicate **flow of control** between main() and the function
- Add **function prototype** at top of program, before main() function

Writing Functions (4/5)

The complete program

Unit5_FunctionEg.c

```
#include <stdio.h>
#include <math.h>

/* Function prototype placed at top of program */
double sqrt_sum_square(double, double);

int main(void) {
    double y = 1.23;    // not the same as y in sqrt_sum_square
    double z = 4.56;

    // x below has nothing to do with x in sqrt_sum_square
    double x = sqrt_sum_square( y, z );
    // in the previous statement, y and z are actual parameters

    printf("The square root of the sum of squares ");
    printf("of %.2f and %.2f is %.2f\n", y, z, x);

    return 0;
}

/* Finds the square root of the
 * sum of the squares of the two parameters
 * Precond: x and y are non-negative numbers
 */
double sqrt_sum_square(double x, double y) {
    // x and y above are the formal parameters

    double sum_square; // local variable declaration

    sum_square = pow(x,2) + pow(y,2);
    return sqrt(sum_square);
}
```


Writing Functions (5/5)

- Use of functions allow us to manage a complex (abstract) task with a number of simple (specific) ones.
 - This allows us to switch between **abstract** and go to **specific** at ease to eventually solve the problem.
- Function allows a team of programmers **working together** on a large program – each programmer will be responsible for a particular set of functions.
- Function is good mechanism to allow **re-use** across different programs. Programmers use functions like **building blocks**.
- Function allows **incremental implementation** and **testing** (with the use of **driver** function to call the function and then to check the output)
- Acronym **NOT** summarizes the requirements for argument list correspondence. (**N**: number of arguments, **O**: order, and **T**: type).

Ex #1: A Simple “Drawing” Program (1/3)

Problem:

- Write a program `Unit5_DrawFigures.c` to draw a rocket ship (which is a triangle over a rectangle over an inverted V), a male stick figure (a circle over a rectangle over an inverted V), and a female stick figure (a circle over a triangle over an inverted V)



rocket



male



female

Analysis:

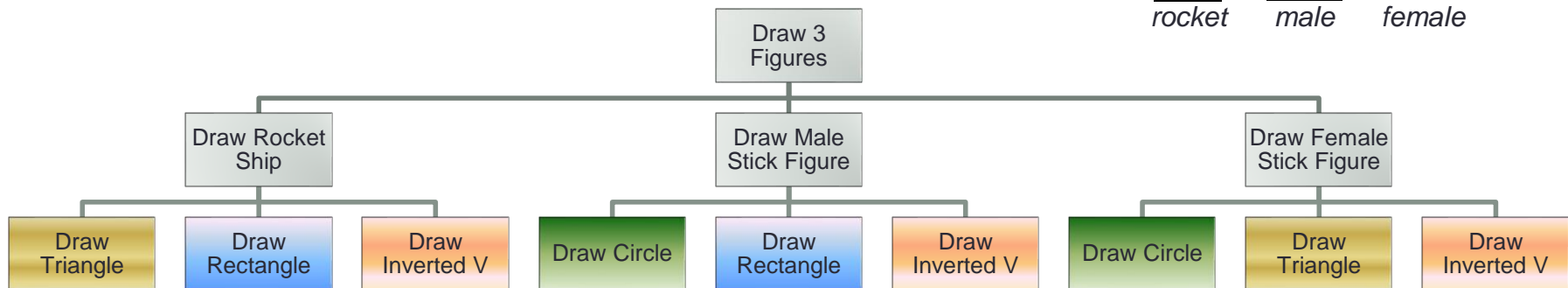
- No particular input needed, just draw the needed 3 figures
- There are common shapes shared by the 3 figures

Design:

- Algorithm (in words):
 1. Draw Rocket ship
 2. Draw Male stick figure (below Rocket ship)
 3. Draw Female stick figure (below Male stick figure)

Ex #1: A Simple “Drawing” Program (2/3)

Design (Structure Chart):



rocket



male



female

Ex #1: A Simple “Drawing” Program (3/3)

Implementation (partial program)

Unit5_DrawFiguresPartial.c

```
#include <stdio.h>

void draw_rocket_ship();
void draw_male_stick_figure();
void draw_circle();
void draw_rectangle();

int main(void) {
    draw_rocket_ship();
    printf("\n\n");

    draw_male_stick_figure();
    printf("\n\n");

    return 0;
}
```

```
void draw_rocket_ship() {
}

void draw_male_stick_figure() {
}

void draw_circle() {
    printf("  **  \n");
    printf(" *    * \n");
    printf(" *    * \n");
    printf("  **  \n");
}

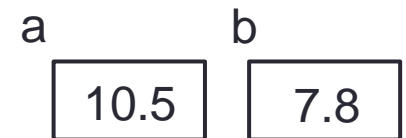
void draw_rectangle() {
    printf(" ***** \n");
    printf(" *      * \n");
    printf(" *      * \n");
    printf(" *      * \n");
    printf(" ***** \n");
}
```

Write a complete program
Unit5_DrawFigures.c

Pass-By-Value and Scope Rules (1/4)

- In C, the actual parameters are passed to the formal parameters by a mechanism known as **pass-by-value**.

```
int main(void) {
    double a = 10.5, b = 7.8;
    → printf("%.2f\n", sqrt_sum_square(3.2, 12/5));
    → printf("%.2f\n", sqrt_sum_square(a, a+b));
    return 0;
}
```



Actual parameters:
10.5 and 20.3

```
double sqrt_sum_square(double x, double y) {
    double sum_square;
    sum_square = pow(x,2) + pow(y,2);
    return sqrt(sum_square);
}
```

Formal parameters:



Pass-By-Value and Scope Rules (2/4)

- Formal parameters are local to the function they are declared in.
- Variables declared within the function are also local to the function.
- Local parameters and variables are only accessible in the function they are declared – scope rule.
- When a function is called, an activation record is created in the call stack, and memory is allocated for the local parameters and variables of the function.
- Once the function is done, the activation record is removed, and memory allocated for the local parameters and variables is released.
- Hence, local parameters and variables of a function exist in memory only during the execution of the function. They are called automatic variables.
- In contrast, static variables exist in the memory even after the function is executed. (We will not use static variables in CS1010.)

Pass-By-Value and Scope Rules (3/4)

- Spot the error in this code:

```
int f(int) ;  
  
int main(void) {  
    int a;  
    ...  
}  
  
int f(int x) {  
    return a + x;  
}
```



Pass-By-Value and Scope Rules (4/4)

- Trace this code by hand and write out its output.

```
#include <stdio.h>
void g(int, int);

int main(void) {
    int a = 2, b = 3;

    printf("In main, before: a=%d, b=%d\n", a, b);
    g(a, b);
    printf("In main, after : a=%d, b=%d\n", a, b);
    return 0;
}

void g(int a, int b) {
    printf("In g, before: a=%d, b=%d\n", a, b);
    a = 100 + a;
    b = 200 + b;
    printf("In g, after : a=%d, b=%d\n", a, b);
}
```



Consequence of Pass-By-Value

- Can this code be used to swap the values in **a** and **b**?

```
#include <stdio.h>
void swap(int, int);

int main(void) {
    int a = 2, b = 3;

    printf("In main, before: a=%d, b=%d\n", a, b);
    swap(a, b);
    printf("In main, after : a=%d, b=%d\n", a, b);
    return 0;
}

void swap(int a, int b) {
    int temp = a;
    a = b;
    b = temp;
}
```



Writing Pre-Condition


- The function `triangle_area()` computes the area of a right-angled triangle. The two parameters are the lengths of the two perpendicular sides.
- How should you write the pre-condition?

```
// Compute the area of a right-angled triangle.  
// side1 and side2 are the lengths of the  
// two perpendicular sides.  
// Pre-cond:  side1 > 0, side2 > 0  
double triangle_area(double side1, double side2) {  
    return side1 * side2 / 2.0;  
}
```



Function Cohesion

- Which of the two approaches is correct?

```
// Compute the area of a right-angled triangle.  
// Pre-cond: side1 > 0, side2 > 0  
double triangle_area(double side1, double side2) {  
    return side1 * side2 / 2.0;  
}
```



```
// Compute the area of a right-angled triangle.  
// Pre-cond: side1 > 0, side2 > 0  
void triangle_area(double side1, double side2) {  
    printf("Area = %.2f\n", side1 * side2 / 2.0);  
}
```



- In general, a function should perform either computation or I/O, not both. `triangle_area()` is to compute the area, so it should return the answer to the caller, which then decides whether to print the answer or use it for further computation in a bigger task.

Global Variables (1/2)

- Global variables are those that are declared outside all functions.

```
int f1(int);  
void f2(double);  
  
int glob; // global variable  
  
int main(void) {  
    ...  
    glob = glob + 1;  
}  
  
int f1(int x) {  
    ...  
    glob = glob + 1;  
}  
  
void f2(double x) {  
    ...  
    glob = glob + 1;  
}
```


Global Variables (2/2)

- Global variables can be accessed and modified by any function!
- Because of this, it is hard to trace when and where the global variables are modified.
- Hence, we will NOT allow the use of global variables

Summary

- In this unit, you have learned about
 - Top-down design through stepwise refinement, splitting a task into smaller sub-tasks
 - How to write user-defined functions and use them
 - Pass-by-value and scope rules of local parameters and variables

End of File