

EECS 10: Computational Methods in Electrical and Computer Engineering

Lecture 14

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Lecture 14: Overview

- Recursion
 - Concept of recursion
 - Recursion vs. iteration
 - Examples
 - Factorial function: `Factorial.c`
 - Fibonacci series: `Fibonacci.c`
- Data Structures
 - Structures, unions, enumerators
 - Type definitions
 - Example
 - Student records: `Students.c`

Recursion

- Introduction
 - *Recursion* is often an alternative to *Iteration*
 - Recursion is a very simple concept, yet very powerful
 - Recursion is present in nature
 - Trees have branches, which have branches, which have branches, ... which have leaves.
 - Recursion is traversal of hierarchy
 - *Traverse* (climb) a tree to the top:
 - start at the root
 - at a leaf, stop
 - at a branch, *traverse* one branch
 - *Traverse* a file system on a computer
 - start at the current directory
 - at a file, process the file
 - at a directory, *traverse* the directory

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Recursion

- Recursive Function
 - Function that calls itself
 - ... directly, or
 - ... indirectly
- Concept of Recursion
 - Trivial *base case*
 - Return value defined for simple case
 - Example: `if (param==0) {return 1;}`
 - *Recursion step*
 - Reduce the problem towards the base case
 - Make a recursive function call
 - Example: `if (param>0) {return ...fct(param-1);}`
- Termination of Recursion
 - Converging of recursive calls to the base case
 - Recursive call must be “simpler” than current call

```
int f(...)
{ ...
  f(...);
  ...
}
```

```
int a(...)
{ ...
  b(...);
  ...
}
int b(...)
{ ...
  a(...);
  ...
}
```

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Recursion

- Example: Factorial function $n!$
 - The factorial of a non-negative integer is
 - $n! = n * (n-1) * (n-2) * (n-3) * \dots * 1$
 - This can be written as
 - $n! = n * ((n-1) * ((n-2) * ((n-3) * (\dots * 1))))$
 - Recursive definition:
 - $n=1: 1! = 1$ (base case)
 - $n>1: n! = n * (n-1)!$ (recursion step)
 - Example computation:

$$\begin{aligned}
 5! &= 5 * 4! \\
 &= 5 * (4 * 3!) \\
 &= 5 * (4 * (3 * 2!)) \\
 &= 5 * (4 * (3 * (2 * 1!))) \\
 &= 5 * (4 * (3 * (2 * 1))) \\
 &= 5 * (4 * (3 * 2)) \\
 &= 5 * (4 * 6) \\
 &= 5 * 24 \\
 &= 120
 \end{aligned}$$

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Recursion

- Program example: `Factorial.c` (part 1/2)

```

/* Factorial.c: example demonstrating recursion */
/* author: Rainer Doemer */
/* modifications: */
/* 11/14/04 RD initial version */

#include <stdio.h>

/* function definition */
long factorial(long n)
{
    if (n == 1) /* base case */
    { return 1;
      } /* fi */
    else /* recursion step */
    { return n * factorial(n-1);
      } /* esle */
} /* end of factorial */

...

```

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Recursion

- Program example: `Factorial.c` (part 2/2)

```
...
int main(void)
{
    /* variable definitions */
    long int n, f;

    /* input section */
    printf("Please enter value n: ");
    scanf("%ld", &n);

    /* computation section */
    f = factorial(n);

    /* output section */
    printf("The factorial of %ld is %ld.\n", n, f);

    /* exit */
    return 0;
} /* end of main */

/* EOF */
```

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Recursion

- Example session: `Factorial.c`

```
% vi Factorial.c
% gcc Factorial.c -o Factorial -Wall -ansi
% ./Factorial
Please enter value n: 1
The factorial of 1 is 1.
% ./Factorial
Please enter value n: 2
The factorial of 2 is 2.
% ./Factorial
Please enter value n: 3
The factorial of 3 is 6.
% ./Factorial
Please enter value n: 5
The factorial of 5 is 120.
% ./Factorial
Please enter value n: 10
The factorial of 10 is 3628800.
%
```

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Recursion vs. Iteration

- Example: Factorial function $n!$
 - The factorial of a non-negative integer is
 - $n! = n * (n-1) * (n-2) * (n-3) * \dots * 1$
 - This can be written as
 - $n! = n * ((n-1) * ((n-2) * ((n-3) * (\dots * 1))))$
 - *Recursive* definition:
 - $n=1: 1! = 1$ (base case)
 - $n>1: n! = n * (n-1)!$ (recursion step)
 - *Iterative* implementation:
 - Compute n products in a loop
 - $n! = n * (n-1) * (n-2) * (n-3) * \dots * 1$
 - `p = n;`
 - `for (f=n-1; f>=1; f--)`
 - `{ p = p * f; }`

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Recursion vs. Iteration

- Program example: `Factorial2.c` (part 1/2)

```

/* Factorial2.c: example demonstrating iteration */
/* author: Rainer Doemer */
/* modifications: */
/* 11/14/04 RD initial version (based on Factorial.c) */
#include <stdio.h>

/* function definition */
long factorial(long n)
{
    long product, factor;
    product = n;
    for(factor = n-1; factor >= 1; factor--)
    { product *= factor;
      } /* rof */
    return product;
} /* end of factorial */

...

```

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Recursion vs. Iteration

- Program example: `Factorial2.c` (part 2/2)

```

...
int main(void)
{
    /* variable definitions */
    long int n, f;

    /* input section */
    printf("Please enter value n: ");
    scanf("%ld", &n);

    /* computation section */
    f = factorial(n);

    /* output section */
    printf("The factorial of %ld is %ld.\n", n, f);

    /* exit */
    return 0;
} /* end of main */

/* EOF */

```

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Recursion vs. Iteration

- Example session: `Factorial2.c`

```

% cp Factorial.c Factorial2.c
% vi Factorial2.c
% gcc Factorial2.c -o Factorial2 -Wall -ansi
% ./Factorial2
Please enter value n: 1
The factorial of 1 is 1.
% ./Factorial2
Please enter value n: 2
The factorial of 2 is 2.
% ./Factorial2
Please enter value n: 3
The factorial of 3 is 6.
% ./Factorial2
Please enter value n: 5
The factorial of 5 is 120.
% ./Factorial2
Please enter value n: 10
The factorial of 10 is 3628800.
%

```

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Recursion

- Example 2: Fibonacci series
 - Sequence of integers
 - 0, 1, 1, 2, 3, 5, 8, 13, 21, 34, 55, 89, 144, 233, 377, 610, 987, ...
 - Mathematical properties
 - The first two numbers are 0 and 1
 - Every subsequent Fibonacci number is the sum of the previous two Fibonacci numbers
 - Ratio of successive Fibonacci numbers is ...
 - ... converging to constant value 1.618...
 - ... called *Golden Ratio* or *Golden Mean*
 - Recursive definition:
 - Base case: $fibonacci(0) = 0$
 $fibonacci(1) = 1$
 - Recursion step: $fibonacci(n) = fibonacci(n-1) + fibonacci(n-2)$

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Recursion

- Program example: `Fibonacci.c` (part 1/2)

```

/* Fibonacci.c: example demonstrating recursion */
/* author: Rainer Doemer */
/* modifications: */
/* 11/14/04 RD initial version */

#include <stdio.h>

/* function definition */
long fibonacci(long n)
{
    if (n <= 1) /* base case */
    { return n;
      } /* fi */
    else /* recursion step */
    { return fibonacci(n-1) + fibonacci(n-2);
      } /* esle */
} /* end of fibonacci */

/* main function */
...

```

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Recursion

- Program example: `Fibonacci.c` (part 2/2)

```

...
int main(void)
{
    /* variable definitions */
    long int n, f;

    /* input section */
    printf("Please enter value n: ");
    scanf("%ld", &n);

    /* computation section */
    f = fibonacci(n);

    /* output section */
    printf("The %ld-th Fibonacci number is %ld.\n", n, f);

    /* exit */
    return 0;
} /* end of main */

/* EOF */

```

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Recursion

- Example session: `Fibonacci.c`

```

% cp Factorial.c Fibonacci.c
% vi Fibonacci.c
% gcc Fibonacci.c -o Fibonacci -Wall -ansi
% ./Fibonacci
Please enter value n: 1
The 1-th Fibonacci number is 1.
% ./Fibonacci
Please enter value n: 10
The 10-th Fibonacci number is 55.
% ./Fibonacci
Please enter value n: 20
The 20-th Fibonacci number is 6765.
% ./Fibonacci
Please enter value n: 30
The 30-th Fibonacci number is 832040.
% ./Fibonacci
Please enter value n: 40
The 40-th Fibonacci number is 102334155.
%

```

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Data Structures

- Structures (aka. records): **struct**
 - User-defined, composite data type
 - Type is a composition of (different) sub-types
 - Fixed set of members
 - Names and types of members are fixed at structure definition
 - Member access by name
 - Member-access operator: *structure_name.member_name*
- Example:

```
struct S { int i; float f;} s1, s2;

s1.i = 42;      /* access to members */
s1.f = 3.1415;
s2 = s1;       /* assignment */
s1.i = s1.i + 2*s2.i;
```

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Data Structures

- Structure Declaration
 - Declaration of a user-defined data type
- Structure Definition
 - Definition of structure members and their type
- Structure Instantiation and Initialization
 - Definition of a variable of structure type
 - Initializer list defines initial values of members
- Example:

```
struct Student;      /* declaration */

struct Student      /* definition */
{ int ID;           /* members */
  char Name[40];
  char Grade;
};

struct Student Jane = /* instantiation */
{1001, "Jane Doe", 'A'}; /* initialization */
```

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Data Structures

- Structure Access
 - Members are accessed by their name
 - Member-access operator .
- Example:

```

struct Student
{
    int ID;
    char Name[40];
    char Grade;
};

struct Student Jane =
{1001, "Jane Doe", 'A'};

void PrintStudent(struct Student s)
{
    printf("ID:    %d\n", s.ID);
    printf("Name:   %s\n", s.Name);
    printf("Grade:  %c\n", s.Grade);
}

```

Jane	
ID	1001
Name	"Jane Doe"
Grade	'A'

```

ID:    1001
Name:  Jane Doe
Grade: A

```

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Data Structures

- Unions: **union**
 - User-defined, composite data type
 - Type is a composition of (different) sub-types
 - Fixed set of *mutually exclusive* members
 - Names and types of members are fixed at union definition
 - Member access by name
 - Member-access operator: `union_name.member_name`
 - *Only one member may be used at a time!*
 - *All members share the same location in memory!*
- Example:

```

union U { int i; float f;} u1, u2;

u1.i = 42;      /* access to members */
u2.f = 3.1415;
u1.f = u2.f;    /* destroys u1.i! */

```

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Data Structures

- Union Declaration
 - Declaration of a user-defined data type
- Union Definition
 - Definition of union members and their type
- Union Instantiation and Initialization
 - Definition of a variable of union type
 - *Single* initializer defines value of *first* member
- Example:

```
union HeightOfTriangle; /* declaration */
union HeightOfTriangle /* definition */
{ int Height; /* members */
  int LengthOfSideA;
  float AngleBeta;
};
union HeightOfTriangle H /* instantiation */
= { 42 }; /* initialization */
```

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Data Structures

- Union Access
 - Members are accessed by their name
 - Member-access operator .
- Example:

```
union HeightOfTriangle
{ int Height;
  int SideA;
  float Beta;
};
union HeightOfTriangle t1, t2, t3
= { 42 };
```

Height/	t1
SideA/	0
Beta	
Height/	t2
SideA/	0
Beta	
Height/	t3
SideA/	42
Beta	

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Data Structures

- Union Access
 - Members are accessed by their name
 - Member-access operator .
- Example:

```
union HeightOfTriangle
{ int   Height;
  int   SideA;
  float Beta;
};

union HeightOfTriangle t1, t2, t3
= { 42 };

void SetHeight(void)
{
  t1.Height = 10;
  t2.SideA = t1.Height / 2;
  t3.Beta = 90.0;
}
```

	t1
Height/	
SideA/	10
Beta	
	t2
Height/	
SideA/	5
Beta	
	t3
Height/	
SideA/	90.0
Beta	

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Data Structures

- Enumerators: **enum**
 - User-defined data type
 - Members are an enumeration of integral constants
 - Fixed set of members
 - Names and values of members are fixed at enumerator definition
 - Members are constants
 - Member values cannot be changed after definition
- Example:

```
enum E { red, yellow, green };
enum E LightNS, LightEW;

LightEW = green;          /* assignment */
if (LightNS == green)    /* comparison */
  { LightEW = red; }
```

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Data Structures

- Enumerator Declaration
 - Declaration of a user-defined data type
- Enumerator Definition
 - Definition of enumerator members and their value
- Enumerator Instantiation and Initialization
 - Definition of a variable of enumerator type
 - Initializer should be one member of the enumerator
- Example:

```
enum Weekday;           /* declaration */
enum Weekday           /* definition */
{ Monday, Tuesday,    /* members */
  Wednesday, Thursday,
  Friday, Saturday, Sunday
};
enum Weekday Today     /* instantiation */
= Tuesday;            /* initialization */
```

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Data Structures

- Enumerator Values
 - Enumerators are represented as integer constants
 - By default, enumerator values start at 0 and are incremented by 1 for each following member
- Example:

Today

Tuesday

Day: 1

```
enum Weekday
{ Monday,
  Tuesday,
  Wednesday,
  Thursday,
  Friday,
  Saturday,
  Sunday
};
enum Weekday Today
= Tuesday;
void PrintWeekday(
    enum Weekday d)
{
    printf("Day: %d\n", d);
}
```

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Data Structures

- Enumerator Values
 - Enumerators are represented as integer constants
 - By default, enumerator values start at 0 and are incremented by 1 for each following member
 - Specific enumerator values may be defined by the user
- Example:

Today

Tuesday

Day: 2

```
enum Weekday
{ Monday = 1,
  Tuesday,
  Wednesday,
  Thursday,
  Friday,
  Saturday,
  Sunday
};

enum Weekday Today
= Tuesday;

void PrintWeekday(
    enum Weekday d)
{
    printf("Day: %d\n", d);
}
```

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Data Structures

- Enumerator Values
 - Enumerators are represented as integer constants
 - By default, enumerator values start at 0 and are incremented by 1 for each following member
 - Specific enumerator values may be defined by the user
- Example:

Today

Tuesday

Day: 3

```
enum Weekday
{ Monday = 2,
  Tuesday,
  Wednesday,
  Thursday,
  Friday,
  Saturday,
  Sunday = 1
};

enum Weekday Today
= Tuesday;

void PrintWeekday(
    enum Weekday d)
{
    printf("Day: %d\n", d);
}
```

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Data Structures

- Type definitions: **typedef**
 - A *typedef* can be defined as an alias type for another type
 - A *typedef* definition follows the same rules as a variable definition
 - Type definitions are usually used to abbreviate access to user-defined types
- Examples:

```
typedef signed long int MyInteger;
MyInteger i1 = 42;

typedef enum Weekday Day;
Day Today = Tuesday;

typedef struct Student Scholar;
Scholar Jane, John;
```

Data Structures

- Program example: **students.c** (part 1/6)

```
/* Students.c: simple array of student records */
/* author: Rainer Doemer */
/* modifications: */
/* 08/28/13 RD initial version */

#include <stdio.h>
#include <stdlib.h>

/* constants */

#define SLEN 40
#define MAX 100

/* data structures */

struct Student
{
    int ID;
    char Name[SLEN];
    int Score;
};
typedef struct Student STUDENT;

STUDENT Record[MAX];
int N = 0;
...
```

Data Structures

- Program example: `students.c` (part 2/6)

```

...
/* function declarations */
STUDENT EnterStudent(void);
void PrintStudent(STUDENT s);
char LetterGrade(int Score);
void InsertStudent(STUDENT s);

/* function definitions */
STUDENT EnterStudent(void)
{
    STUDENT s;

    printf("Enter student ID:   ");
    scanf("%d", &s.ID);
    printf("Enter student name: ");
    scanf("%39s", &s.Name[0]);
    printf("Enter student score: ");
    scanf("%d", &s.Score);
    return s;
}
...

```

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Data Structures

- Program example: `students.c` (part 3/6)

```

...
void PrintStudent(STUDENT s)
{
    printf("ID %3d: %-39s, Score %3d%% = %c\n",
          s.ID, s.Name, s.Score, LetterGrade(s.Score));
}

char LetterGrade(int Score)
{
    switch(Score/10)
    {
        case 10:
        case 9: return 'A';
        case 8: return 'B';
        case 7: return 'C';
        case 6: return 'D';
        case 5: case 4: case 3: case 2: case 1:
        case 0: return 'F';
        default: break;
    } /* hctiws */
    return '-';
}
...

```

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Data Structures

- Program example: `students.c` (part 4/6)

```

...
void InsertStudent(STUDENT s)
{
    int i, j;

    for(i=0; i<N; i++)
    {
        if (s.ID < Record[i].ID)
        { break;
        }
    }
    for(j=N; j>i; j--)
    {
        Record[j] = Record[j-1];
    }
    Record[i] = s;
    N++;
}
...

```

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Data Structures

- Program example: `students.c` (part 5/6)

```

...
int main(void)
{
    int Choice, i;

    while(1)
    { printf("Student records: %d\n", N);
      printf("1. Enter new student\n");
      printf("2. Print student table\n");
      printf("3. Quit\n");
      printf("Choice: ");
      scanf("%d", &Choice);
      switch(Choice)
      { case 1:
        { if (N < MAX)
          { InsertStudent(EnterStudent());
          }
          break;
        }
      }
    }
}
...

```

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Data Structures

- Program example: `students.c` (part 6/6)

```

...
    case 2:
    {   for(i=0; i<N; i++)
        { PrintStudent(Record[i]);
          }
        break;
    }
    case 3:
    {   exit(0);
        }
    default:
    {   break;
        }
    } /* hctiws */
} /* elihw */
return 0;
} /* end of main */

/* EOF */

```

Data Structures

- Example session: `students.c` (part 1/3)

```

% vi Students.c
% gcc Students.c -o Students -Wall -ansi
% ./Students
Student records: 0
1. Enter new student
2. Print student table
3. Quit
Choice: 1
Enter student ID:   1879
Enter student name: Albert_Einstein
Enter student score: 100
Student records: 1
1. Enter new student
2. Print student table
3. Quit
Choice: 2
ID 1879: Albert_Einstein           , Score 100% = A
...

```

Data Structures

- Example session: `students.c` (part 2/3)

```

...
Student records: 1
1. Enter new student
2. Print student table
3. Quit
Choice: 1
Enter student ID: 1642
Enter student name: Isaac_Newton
Enter student score: 100
Student records: 2
1. Enter new student
2. Print student table
3. Quit
Choice: 2
ID 1642: Isaac_Newton , Score 100% = A
ID 1879: Albert_Einstein , Score 100% = A
...

```

Data Structures

- Example session: `students.c` (part 3/3)

```

[...]
Choice: 1
Enter student ID: 1623
Enter student name: Blaise_Pascal
Enter student score: 100
Student records: 3
1. Enter new student
2. Print student table
3. Quit
Choice: 2
ID 1623: Blaise_Pascal , Score 100% = A
ID 1642: Isaac_Newton , Score 100% = A
ID 1879: Albert_Einstein , Score 100% = A
Student records: 3
1. Enter new student
2. Print student table
3. Quit
Choice: 3
%

```