Recursion – Union

Basics of Programming 1

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NETWORKED SYSTEMS
AND SERVICES

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Content

Chapter 1

Recursion

Recursion – definition

Many mathematical problems can be formulated recursively

- Sum of sequence a_n

$$S_n = \begin{cases} S_{n-1} + a_n & n > 0 \\ a_0 & n = 0 \end{cases}$$

- Factorial

$$n! = \begin{cases} (n-1)! \cdot n & n > 0 \\ 1 & n = 0 \end{cases}$$

- Fibonacci numbers

$$F_n = \begin{cases} F_{n-2} + F_{n-1} & n > 1 \\ 1 & n = 1 \\ 0 & n = 0 \end{cases}$$

Recursion – definition

Several everyday problems can be formulated recursively

- Is Albert Einstein my ancestor?

$$\text{My ancestor?} = \begin{cases} \text{Ancestor of my father/mother?} \\ \text{Is he my father?} \\ \text{Is she my mother?} \end{cases}$$

- In general

$$\text{Problem} = \begin{cases} \text{Simpler, similar problem(s)} \\ \text{Trivial case(es)} \end{cases}$$

Recursion – outlook

- Recursion is useful in many areas
  - Mathematical proof e.g., proof by induction
  - Definition e.g., Fibonacci numbers
  - Algorithm e.g., path finding algorithms
  - Data structure e.g., linked list, folders of the op. system
  - Geometric constructions e.g., fractals
- We are going to study recursive data structures and recursive algorithms

Recursive algorithms in C

- Factorial

$$n! = \begin{cases} (n-1)! \cdot n & n > 0 \\ 1 & n = 0 \end{cases}$$

Let us implement it to C!

```c
unsigned factorial(unsigned n)
{
  if (n > 0)
    return factorial(n-1) * n;
  else
    return 1;
}
```

- Calling the function

```c
unsigned f = factorial(5); /* it works! */
printf("%u\n", f);
```

Some considerations

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- How to imagine recursive functions?

```
unsigned f0(void) { return 1; }
unsigned f1(void) { return f0() * 1; }
unsigned f2(void) { return f1() * 2; }
unsigned f3(void) { return f2() * 3; }
unsigned f4(void) { return f3() * 4; }
unsigned f5(void) { return f4() * 5; }
...
unsigned f = f5();
```

- Many different instances of the same function coexist simultaneously
- The instances were called with different parameters

Implementing recursion

How can multiple instances of the same function coexist?

```
/*
  recursive factorial function
 */
unsigned factorial(unsigned n)
{
  if (n > 0)
    return factorial(n-1) * n;
  else
    return 1;
}

int main(void)
{
  ...
   factorial(4);
  ...
}
```

register: 24

Implementing recursion

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- The mechanism of the function calls in C is capable of writing recursive functions
- All the data (local variables, return addresses) of the calling functions are stored in the stack
- Whether the function calls itself or an other function makes no difference
- The maximal depth of recursive calls: given by the stack size

Recursion or iteration – factorial

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Calculating *n*! recursively – elegant, but inefficient

```
unsigned fact_rec(unsigned n)
{
  if (n == 0)
    return 1;
  return fact_rec(n-1) * n;
}
```

link

and iteratively – boring, but efficient

```
unsigned fact_iter(unsigned n)
{
  unsigned f = 1, i;
  for (i = 2; i <= n; ++i)
    f *= i;
  return f;
}
```

link

Recursion or iteration – Fibonacci

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Calculating F_n recursively – elegant, but way too slow!

```
unsigned fib_rec(unsigned n)
{
  if (n <= 1)
    return n;
  return fib_rec(n-1) + fib_rec(n-2);
}
```

link

and iteratively – boring, but efficient

```
unsigned fib_iter(unsigned n)
{
  unsigned f1 = 0, f2 = 1, f3, i;
  for (i = 2; i <= n; ++i) {
      f3 = f1 + f2;
      f1 = f2;
      f2 = f3;
  }
  return f2;
}
```

link

Recursion or iteration

1. Every recursive algorithm can be transformed to an iterative one (loops)
   - There is no general method for this transformation
2. Every iterative algorithm can be transformed to a recursive one
   - Easy to do systematically, but usually not efficient

There is no universal truth: the choice between recursive and iterative algorithms depends on the problem

Iterative algorithms recursively

Traversing arrays recursively (without loops)

```c
void print_array(int* array, int n)
{
  if (n == 0)
    return;
  printf("%d ", array[0]);
  print_array(array+1, n-1); /* recursive call */
}
```

Traversing strings recursively

```c
void print_string(char* str)
{
  if (str[0] == '\0')
    return;
  printf("%c", str[0]);
  print_string(str+1); /* recursive call */
}
```

Printing number in a given numeral system

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recursively

```
void print_base_rec(unsigned n, unsigned base)
{
  if (n >= base)
    print_base_rec(n/base, base);
  printf("%d", n%base);
}
```

link

iteratively

```
void print_base_iter(unsigned n, unsigned base)
{
  unsigned d; /* power of base not greater than n */
  for (d = 1; d*base <= n; d*=base);
  while (d > 0)
  {
    printf("%d", (n/d)%base);
    d /= base;
  }
}
```

link

When the recursive algorithm is definitely better

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The array below stores a labyrinth

```c
char lab[9][9+1] = {
  "+-------+",
  "|       |",
  "+-+ ++ ++",
  "|       |",
  "| + +-+ |",
  "| | |   |",
  "+-+ +-+ |",
  "|     | |",
  "+-----+-+"
};
```

link

Let us visit the entire labyrinth from start position (x,y)

```c
traverse(lab, 1, 1);
```

We go in every possible direction and visit the yet unvisited parts of the labyrinth

When the recursive algorithm is definitely better

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The simplicity of the recursive solution is striking

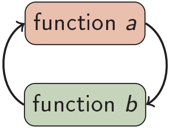
```c
void traverse(char lab[][9+1], int x, int y)
{
  lab[x][y] = '.';          /* mark that we were here */
  if (lab[x-1][y] == ' ') /* go upwards, if needed */
    traverse(lab, x-1, y);
  if (lab[x+1][y] == ' ') /* go downwards, if needed */
    traverse(lab, x+1, y);
  if (lab[x][y-1] == ' ') /* go left, if needed */
    traverse(lab, x, y-1);
  if (lab[x][y+1] == ' ') /* go right, if needed */
    traverse(lab, x, y+1);
}
```

link

It is also possible to do with an iterative algorithm – but it is much more complex

Indirect recursion

Indirect recursion: Functions mutually call each other




```c
/* forward declaration */
void b(int); /* name, return type, parameter types */

void a(int n) {
  ...
  b(n); /* b can be called due to the forward decl. */
  ...
}

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

Forward declaration

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Forward declaration will be necessary for recursive data structures

```c
/* forward declaration */
struct child_s;

struct mother_s { /* mother type */
  char name[50];
  struct child_s *children[20]; /*pntr. arr. of children*/
};

struct child_s { /* child type */
  char name[50];
  struct mother_s *mother; /*pointer to the mother*/
};
```

Chapter 2

Union and bitfield

Union data type

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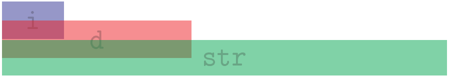
Union

Simple data type capable of storing data of different types

```
union data {
  short int i;  /* overlapped memory layout !!! */
  double d;
  char str[20];
};
```

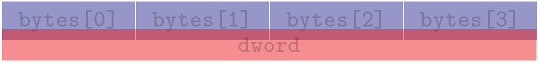



```
union data a;
strcpy(a.str, "Hello world");
printf("%f", a.d);  /* first 8 bytes as a double */
```

The size of the type is determined by the longest member

Typical application


```c
union data {
  unsigned char bytes[4];
  unsigned int dword;
};
```




```c
union data a;
a.dword = 234568;
printf("%u", a.bytes[2]);
```

The sample code is correct only if the size of `unsigned int` is at least 32 bits

An other typical application


```c
typedef struct { double x1, x2, y1, y2; } line_t;
typedef struct { double x0, y0, r; } circle_t;

typedef struct {
  enum {LINE, CIRCLE} type; /* what is inside */
  union { /* this part is EITHER a line OR a circle */
    line_t line;
    circle_t circle;
  };
} object_t;
```

```c
object_t array[4];
```


```c
array[0].type = LINE;
array[0].line.x1 = 2;
```

Example

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L	line	C	circle	L	line	L	line

```
for (i = 0; i < 4; ++i) {
  if (array[i].type == LINE) {
    line_t line = array[i].line;
    /* process line */
  }
  else if (array[i].type == CIRCLE) {
    circle_t circle = array[i].circle;
    /* circle processing */
  }
}
```

Bitfield data type

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In low level programming it is sometimes useful to work with the bits of a data as individual variables.

		d	c		b	a	
x	x	0	1	0	1	0	1

Bitfield

In a single variable we store several variables.

```c
struct status {
  unsigned a : 2;
  unsigned b : 1;
  unsigned c : 2;
  unsigned d : 1;
};
```

```c
struct status st1;
st1.a = 1;
st1.b = 1;
st1.c = 2;
st1.d = 0;
```

Bitfields can have only `unsigned int` or `int` members

Thank you for your attention.