Pointers – Strings

Basics of Programming 1

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NETWORKED SYSTEMS
AND SERVICES

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Content

Chapter 1

Pointers

Fundamental Theorem of Software Engineering (FTSE)

"We can solve any problem by introducing an extra level of indirection."
Andrew Koenig

Where are the variables?

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Let's write a program that lists the address and value of variables

```
int a = 2;
double b = 8.0;
printf("address of a: %p, its value: %d\n", &a, a);
printf("address of b: %p, its value: %f\n", &b, b);
```

```
address of a: 0x7fffa3a4225c, its value: 2
address of b: 0x7fffa3a42250, its value: 8.000000
```

- address of variable: starting address of "memory block" containing the variable, expressed in bytes
- with the address-of operator we can create address of any variables[1] like this `&<reference>`

[1] more precisely left-values

The pointer type

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The pointer type is for storing memory addresses

Declaration of pointer

<pointed type> * <identifier>;

```
int*    p;  /*  p stores the address of one int data */
double* q;  /*  q stores the address of one double data */
char*   r;  /*  r stores the address of one char data */
```

it is the same, even if arranged in a different way

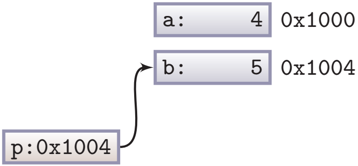
```
int     *p;  /*  p stores the address of one int data */
double  *q;  /*  q stores the address of one double data */
char    *r;  /*  r stores the address of one char data */
```

Operator of indirection

- If pointer p stores the address of variable a, then p ”points to a”
- If p points to a, then variable a can be accessed as *p. Here * is the operator of indirection (dereference operator).

```c
int a, b;
int *p; /* int pointer */

a = 2;
b = 3;
p = &a; /* p points to a */
*p = 4; /* a = 4 */
p = &b; /* p points to b */
*p = 5; /* b = 5 */
```



Address-of and indirection – summary

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operator	operation	description
&	address-of	assigns its address to the variable
*	indirection	assigns variable to the address

- Interpreting declaration: type of *p is int

```
int *p;        /* get used to this version */
```

- Multiple declaration: type of a, *p and *q is int

```
int a, *p, *q; /* at least because of this */
```

Application – Function for exchanging two variables

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```
void xchg(int x, int y) {
  int tmp = x;
  x = y;
  y = tmp;
}

void xchgp(int *px, int *py) {
  int tmp = *px;
  *px = *py;
  *py = tmp;
}

int main(void) {
  int a = 2, b = 3;
  xchg(a, b);
/* NO exchange */
  xchgp(&a, &b);/* exchange */
  return 0;
}
```

Application – returning value as parameter

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- If a function has to calculate several values, then...

  ...we can use structures, but sometimes this seems rather unnecessary.
  Instead...

```
int inverse(double x, double *py)
{
  if (abs(x) < 1e-10) return 0;
  *py = 1.0 / x;
  return 1;
}
```

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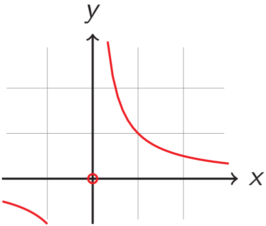


```
double y;          /* memory allocation for result */
if (inverse(5.0, &y) == 1)
  printf("Reciprocal of %f is %f\n", 5.0, y);
else
  printf("Reciprocal does not exist");
```

link

Application – return values as parameters

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- Now we understand what this means

```c
int n, p;
/* return value as parameter */
scanf("%d%d", &n, &p); /* we pass the addresses */
```

Remarks:

- What is the use of having different pointer types for different types?
- Type = set of values + operations
- Obviously set of values is the same for all pointers (unsigned integer addresses)
- Operations are different!
- The operator of indirection (∗)
  - makes `int` from `int` pointer
  - makes `char` from `char` pointer
- Other differences are detailed in pointer-arithmetics...

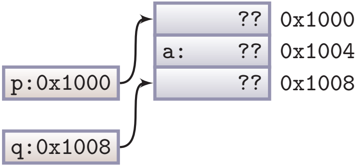
Pointer-arithmetics

If p and q are pointers of the same type, then

expr.	type	meaning
p+1	pointer	points to the next element
p-1	pointer	points to the previous element
q-p	integer number	number of elements between two addresses

```c
int a, *p, *q;

p = &a;
p = p-1;
q = p+2;
printf("%d", q-p);
```




```
2
```

- At pointer-arithmetic operaitons addresses are ”measured” in the representation size of the pointed type, and not in bytes.[2]

[2]In this example we assume that size of int is 4 bytes

Pointer-arithmetic

- In the above example pointer-arithmetic is strange, as we don't know what is before or after variable a in the memory.
- This operation is meaningful, when we have variables of the same type, stored in the memory one afte the other.
- This is the case for arrays.

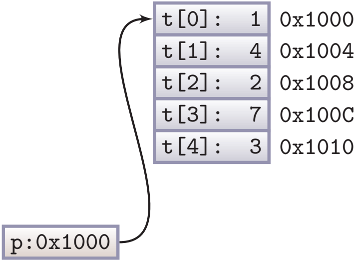
Pointers and arrays

- Traversing an array can be done with pointer-arithmetics.

```c
int t[5] = {1,4,2,7,3};
int *p, i;

p = &t[0];
for (i = 0; i < 5; ++i)
  printf("%d ", *(p+i));
```

```
1 4 2 7 3
```



- In this example `*(p+i)` is the same as `t[i]`, because `p` points to the beginning of array `t`

Pointers and arrays

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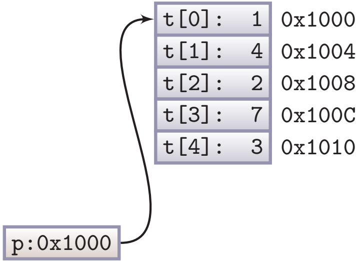
- Pointers can be taken as arrays, this means they can be indexed.
  By definition `p[i]` is identical to `*(p+i)`

```c
int t[5] = {1,4,2,7,3};
int *p, i;

p = &t[0];
for (i = 0; i < 5; ++i)
  printf("%d ", p[i]);
```

```
1 4 2 7 3
```



- In this example `p[i]` is the same as `t[i]`, because `p` points to the beginning of array `t`

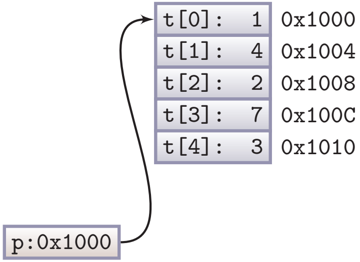
Pointers and arrays

- Arrays can be taken as pointers.
  The identifier (name) of array is the starting address of the array, in other words the value of expression `t` is `&t[0]`

```c
int t[5] = {1,4,2,7,3};
int *p, i;

p = t; /* &t[0] */
for (i = 0; i < 5; ++i)
  printf("%d ", p[i]);
```

```
1 4 2 7 3
```



- Pointer-arithmetics work for arrays too:
  `t+i` is identical to `&t[i]`

Pointers and arrays – summary

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- Pointer can be taken as array, and array as a pointer.
- index operator is only a notation
  the compiler will always replace `a[i]` with `*(a+i)`,
  both if *a* is pointer, and also if *a* is array.
- Differences:
  - Elements of array have allocated space in memory (variables). No allocated elements belong to the pointer.
  - Starting address of array is constant, it cannot be changed. Pointer is a variable, the address stored in it can be modified.

```c
int array[5] = {1, 3, 2, 4, 7};
int *p = array;

/* the elements can be accessed via p and a */
p[0] = 2;                 array[0] = 2;
*p = 2;                   *array = 2;

/* p can be changed   array CANNOT */
p = p+1; /* ok */         array = array + 1; /* ERROR */
```

Passing arrays to functions

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- Let's use a function to determine the first negative element of array!
- Passing an array:
  - Address of first element `double*`
  - Size of the array `typedef unsigned int size_t`[3]

```
double first_negative(double *array, size_t size)
{
  size_t i;
  for (i = 0; i < size; ++i)  /* for each elems. */
    if (array[i] < 0.0)
      return array[i];

  return 0; /* all are non-negative */
}
```

link

```
double myarray[3] = {3.0, 1.0, -2.0};
double neg = first_negative(myarray, 3);
```

link

[3]defined in `stdio.h`

Passing arrays to functions

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- To distinguish arrays and pointers in the parameter list, we can use the array-notation when passing an array.

```
double first_negative(double array[], size_t size)
                    /*  (double *array,  size_t size)  */
{
  ...
}
```

- In the formal parameter list `double a[]` is identical to `double *a`.
- In the formal parameter list we can use only empty `[]`, and size should be passed as a separate parameter!

Passing arrays to functions

- Let's use a function to determine the first negative element of array!
- The return value should be the address of the element found.

```
double *first_negative(double *array, size_t size)
{
  size_t i;
  for (i = 0; i < size; ++i)  /* for each elems. */
    if (array[i] < 0.0)
      return &array[i];

  return NULL; /* all are non-negative */
}
```

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Null pointer

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- The null pointer (`NULL`)
  - It stores the `0x0000` address
  - Agreed that it "points to nowhere"

Chapter 2

Strings

Strings

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- In C, text is stored in character arrays with termination sign, called as strings.
- The termination sign is the character with 0 ASCII-code `'\0'`, the null-character.

'S'	'o'	'm'	'e'	' '	't'	'e'	'x'	't'	'\0'

Defining strings as character arrays

- Definition of character array with initialization

```
char s[] = {'H', 'e', 'l', 'l', 'o', '\0'};
```

- The same in a more simple way

```
char s[] = "Hello"; /* s array (const.addr 0x1000) */
```

'H'	0x1000
'e'	0x1001
'l'	0x1002
'l'	0x1003
'o'	0x1004
'\0'	0x1005

'D'	0x1000
'e'	0x1001
'l'	0x1002
'l'	0x1003
'a'	0x1004
'\0'	0x1005

- Elements of `s` can be accessed with indexing or with pointer-arithmetics

```
*s = 'D';    /* s is taken as pointer */
s[4] = 'a'; /* s is taken as array */
```

Defining strings as character arrays

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- We can allocate memory for a longer string than needed now, thus we have an overhead.

```
char s[10] = "Hello"; /* s array, (const.addr. 0x1000) */
```

'H'	0x1000	'H'	0x1000
'e'	0x1001	'e'	0x1001
'l'	0x1002	'l'	0x1002
'l'	0x1003	'l'	0x1003
'o'	0x1004	'o'	0x1004
'\0'	0x1005	'!'	0x1005
?	0x1006	'!'	0x1006
?	0x1007	'\0'	0x1007
?	0x1008	?	0x1008
?	0x1009	?	0x1009

- Modification:

```
s[5] = s[6] = '!';
s[7] = '\0';          /* must be terminated */
```

Defining strings as character arrays

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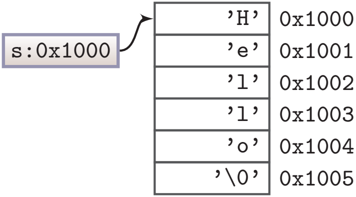
- Defining a constant character array and a pointer pointing to it, with initialization.

```
char *s = "Hello"; /* s pointer */
```



- Here the so-called static part of memory is used to store the string. The content of the string cannot be changed.
- We can modify value of `s`, however it is not recommended, because this stores the address of our string.

Remarks

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- Character or text?

```
char s[] = "A"; /* two bytes: {'A', '\0'} */
char c = 'A';   /* one byte: 'A' */
```

- A text can be empty, but there is no empty character

```
char s[] = "";  /* one byte: {'\0'} */
char c = '';    /* ERROR, this is not possible */
```

Reading and displaying strings

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- Strings are read and displayed with format code %s

```c
char s[100] = "Hello";
printf("%s\n", s);
printf("Enter a word not longer than 99 characters: ");
scanf("%s", s);
printf("%s\n", s);
```

```
Hello
Enter a word not longer than 99 characters:  ghostbusters
ghostbusters
```

- Why don't we have to pass the size for `printf`?
- Why don't we need the `&` in the `scanf` function?

Reading and displaying strings

- scanf reads only until the first whitespace character. To read text consisting of several words, use the gets function:

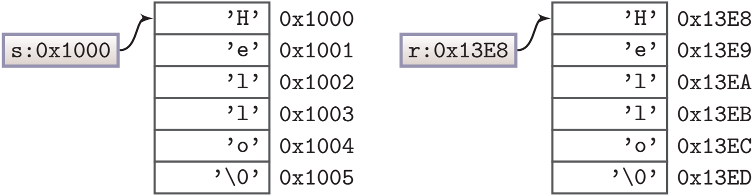
```
char s[100];
printf("Enter a text - max. 99 characters long: ");
gets(s);
printf("%s\n", s);
```

```
Enter a text - max. 99 characters long: this is text
this is text
```

Strings – typical mistakes

- Typical mistake: comparison of strings

```c
char *s = "Hello";
char *r = "Hello";
if (s == r) /* what do we compare? */
  ...
```



- The same mistake happens if defined as arrays

String functions

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- Comparing strings
- the result
  - positive, if s1 stands after s2 alphabetically
  - 0, if they are identical
  - negative, if s1 stands before s2 alphabetically

```c
int strcmp(char *s1, char *s2) /* pointer-notation */
{
  while (*s1 != '\0' && *s1 == *s2)
  {
    s1++;
    s2++;
  }
  return *s1 - *s2;
}
```

- Is it a problem, that s1 and s2 was changed during the check?
- Remark: In the solution we made use of the information that \0 is the 0 ASCII-code character!

Strings – typical mistakes

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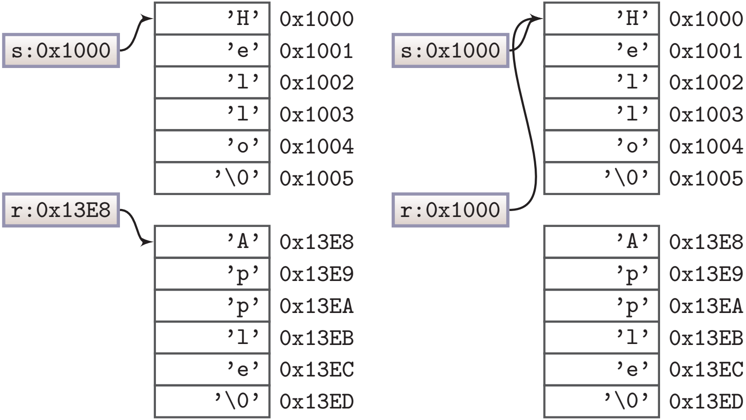
- Typical mistake: string copy attempt

```
char *s = "Hello";
char *r = "Apple";
r = s; /* what do we copy */
```



Other string functions

- `#include <string.h>`
  - `strlen` length of string (without `\0`)
  - `strcmp` comparing strings
  - `strcpy` copying string
  - `strcat` concatenating strings
  - `strchr` search for character in string
  - `strstr` search for string in string
- `strcpy` and `strcat` functions copy 'without thinking', the user must provide the allocated memory for the resulting string!

Chapter 3

The enumerated type

The enumerated type – Motivation

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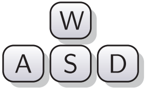
- We are writing a game, in which the user can control direction of the player with 4 keys.



- As the input from user needs to be read (checked) frequently, we create a `read_direction()` function for this task.
- This function reads from the keyboard and returns the direction to the calling program segment.
- What type should the function return with?

The enumerated type – Motivation

- Idea Nr. 1: Let's return with the key pressed. ('a','s','w','d'):

```
char read_direction(void)
{
  char ch;
  scanf("%c", &ch);
  return ch;
}
```

link

- Problems:
  - We have to decode characters into directions many times at different parts of the source code.
  - If we change to use the arrow keys $\leftarrow \downarrow \uparrow \rightarrow$ for control, we have to modify the source code a thousand time and place.
- Solution:
  - We have to decode in place (inside the function), and should return with direction.
  - But how can we do that?

The enumerated type – Motivation

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- Idea Nr. 2: Let's return with `int` values 0,1,2,3:

'a'	0	←
'w'	1	↑
'd'	2	→
's'	3	↓

```c
int read_direction(void) {
  char ch;
  scanf("%c", &ch);
  switch (ch) {
  case 'a': return 0; /* left */
  case 'w': return 1; /* up */
  case 'd': return 2; /* right */
  case 's': return 3; /* down */
  }
  return 0; /* default is left :) */
}
```

- Problem:
  - In other parts of the program we have to use numbers 0-3 for the directions, so the programmer must remember the number-direction assignments.

The enumerated type – Motivation

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- We need a type named `direction`, that can store `LEFT`, `RIGHT`, `UP`, `DOWN` values.
- We can do such thing in C!

  Declaration of the appropriate enumerated type (`enum`):

```c
enum direction {LEFT, RIGHT, UP, DOWN};
```

- How to use the type:

```c
enum direction d;
d = LEFT;
```

The enumerated type – Motivation

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- The final solution with the new type

```
enum direction {LEFT, RIGHT, UP, DOWN};
typedef enum direction direction; /* simplification */

direction read_direction(void)
{
  char ch;
  scanf("%c", &ch);
  switch (ch)
  {
  case 'a': return LEFT;
  case 'w': return UP;
  case 'd': return RIGHT;
  case 's': return DOWN;
  }
  return LEFT;
}
```

link

The enumerated type – Motivation

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- Usage of the function:

```
direction d = read_direction();
if (d == RIGHT)
  printf("You were eaten by a tiger\n");
```

link

- Without the enumerated type, it would look like this:

```
int d = read_direction();
if (d == 2) /* "magic" constant, what does it mean? */
  printf("You were eaten by a tiger\n");
```

link

- The enumerated type...
  - replaces "magic constants" with informative code,
  - focuses on content instead of representation,
  - allows a higher level programming.

The enumerated type – Definition

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The enumerated (enum) type

Joins into one type integer type constants referenced by symbolic names.

```
enum [&lt;enumeration label&gt;]opt
{ <enumeration list> }
[<variable identifiers>]opt;
```

```
enum direction {LEFT, RIGHT, UP, DOWN} dir1, dir2;
```

enum examples

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```
enum month {
  JAN,  /*  0 */
  FEB,  /*  1 */
  MAR,  /*  2 */
  APR,  /*  3 */
  MAY,  /*  4 */
  JUNE, /*  5 */
  JULY, /*  6 */
  AUG,  /*  7 */
  SEPT, /*  8 */
  OCT,  /*  9 */
  NOV,  /* 10 */
  DEC   /* 11 */
};

enum month m=OCT; /*9*/
```

```
enum {
  RED,        /*  0 */
  BLUE = 3,   /*  3 */
  GREEN,      /*  4 */
  YELLOW,     /*  5 */
  GRAY = 10   /* 10 */
} c;

c = GREEN;
printf("c: %d\n", c);
```

```
c:  4
```

Thank you for your attention.