Computer Programming

Pointer Arithmetic. Function Pointers. Dynamic Allocation

Marius Minea

marius@cs.upt.ro

18 November 2014

Arrays and pointers

The *name of an array* is a *constant address*

declaring an array allocates a memory block for its elements

the array's *name* is the *address* of that block (of first element)

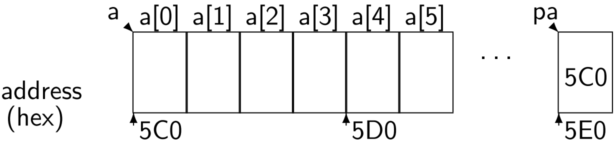
`&a[0]` is same as `a` and `a[0]` is same as `*a`

Can declare *sometyp* `a[LEN], *pa;` and assign `pa = a;`

Similar: `a` and `pa` have same type: *sometyp**

But: `pa` is a *variable* ⇒ uses memory; *can assign* `pa =` *addr*

`a` is a *constant* (array has fixed address) *can't assign* ~~`a =` *addr*~~




```
int a[6];
int *pa = a;
```

`*a` and `*pa`: indirections with different operations in machine code:

`*a` references object from *constant* address (*direct* addressing)

`*pa` must first get *value* of variable `pa` (an address), loading it from the *constant* address `&pa`) *then* dereference it (*indirect* addressing)

Arrays and pointers (cont'd)

In function declarations, these are the same (first becomes second):

`size_t strlen(char s[]);` becomes `size_t strlen(char *s);`

As array declarations they are *different!*

Array: `char s[] = "test";` `s[0]` is `'t'`, `s[4]` is `'\0'` etc.

`s` is a *constant address* (`char *`), not a variable in memory

CANNOT assign `s = ...` but may assign `s[0] = 'f'`

`sizeof(s)` is 5 * `sizeof(char)` `&s` is `s` (but different type)

but with different type, address of 5-char array: `char (*)[5]`

`sizeof` (entire array) is not `strlen` (up to '\0')

Pointer: `char *p = "test";` `p[0]` is `'t'`, `p[4]` is `'\0'` (same)

`p` is a *variable of address type* (`char *`), has a memory location

CANNOT assign ~~`p[0] = 'f'`~~ (`"test"` is a string *constant*)

can do `p = s;` then `p[0] = 'f';` can assign `p = "ana";`

`sizeof(p)` is `sizeof(char *)` `&p` is NOT `p`

⇒ WRONG: ~~`scanf("%4s", &p);`~~ RIGHT: `scanf("%4s", p);`

(if `p` is valid address and has room)

Pointer arithmetic

A variable `v` of a *sometype* takes up `sizeof(`*sometype*`)` bytes

⇒ `&v + 1` is the address *after* the space allocated to `v`

numerically larger than `&v` by `sizeof(`*sometype*`)` bytes

+ on a pointer increments by an *object* (~~not a byte~~)

+ on a street address: advances by one house, not one meter

1. *Add/subtract* pointer and integer: like address of array element

`a + i` means `&a[i]` and `*(a + i)` means `a[i]`   `3[a]` is `a[3]`

increment `++a`, `a++`: `a` becomes `a + 1` before/after evaluation

```
// returns pointer to end of s; stops at null character '\0'
char *endptr(char *s) { while (*s) ++s; return s; }
```

2. *Difference*: only for pointers of *same* type (and in same array!)

= number of objects of *type* that fit between the two addresses

To get the number of bytes, convert pointers to `char *` (type cast):

```
p - q == ((char *)p - (char *)q) / sizeof(type)
```

No other arithmetic operations between pointers are defined!

May use comparison operators (`==`, `!=`, `<`, etc.)

Pointer arithmetic (cont.)

pointer + int = pointer (of same type)

Pointer arithmetic is only valid *within* allocated objects
exception: can take address *just* beyond (at end) of array
`int a[LEN], *end = a + LEN;`

In standard: `a+LEN+1` is *not* a valid address (beyond legal memory)
In practice: runtime won't protect from overflow; think carefully!

Arithmetic is not defined on `void *`. Cast to `char *` to add `int`

Pointer arithmetic and operator precedence
`++` (and `--`) have higher precedence than `*` (indirection)

`*p++` `++` applies to `p`: take value, (post)increment *pointer*
`(*p)++` (post)increments the *value* at address `p`

`*++p` takes value after incrementing pointer
`++*p` increments value at pointer (expression has that value)

Pointers and indices

same meaning: “to indicate” = “to point to”

To write `a[i]`, need two variables and one addition (base + offset)
and multiplication with size of type (if not 1)

Simpler: directly with pointer to element `&a[i]` `(a+i)`
increment pointer rather than index when traversing array

```
char *strchr_i(const char *s, int c) { // search char in s
  for (int i = 0; s[i]; ++i)  // traverse string up to '\0'
    if (s[i] == c) return s + i; // found: return address
  return NULL;                // not found
}

char *strchr_p(const char *s, int c) {
  for ( ;*s; ++s)   // use parameter for traversal
    if (*s == c) return s;     // s points to current char
  return NULL;      // not found
}
```

Pointers and indices (cont'd)

```
char *strcat_i(char *dest, const char *src)
{
  int i = 0, j;
  while (dest[i]) ++i;
  for (j = 0; src[j]; ++j)
    dest[i+j] = src[j];
  dest[i+j] = '\0';
  return dest;
}
char *strcat_p(char *dest, const char *src)
{
  char *d = dest; // need to save dest for return
  while (*d) ++d;
  while (*d++ = *src++);
  return dest;
}
```

Pointers and multidimensional arrays

A bidimensional array (matrix) is declared as *type* `a[DIM1][DIM2];`

`a[i]` is address (const *type* `*`) of an array (line) of `DIM2` elements

`a[i][j]` is `j`th element in array `a[i]` of `DIM2` elements

`&a[i][j]` or `a[i]+j` is `DIM2*i+j` elements after address `a`

⇒ a function with array parameter needs all dimensions except first

⇒ must declare as *funtype* `f(`*eltype* `t[][DIM2]);`

```
char t[12][4]={"jan",...,"dec"};
```

t is matrix (2-D char array)

j	a	n	\0
f	e	b	\0
...			
d	e	c	\0

t uses 12 * 4 bytes

`t[6] = ...` is WRONG

`t[6]` is constant address of line 7

can do `str(n)cpy(t[6], ...)`

```
char *p[12]={"jan",...,"dec";}
```

p is array of pointers

0x460	⟶	j	a	n	\0
0x5C4	⟶	f	e	b	\0
...					
0x9FC	⟶	d	e	c	\0

p uses 12*sizeof(char *) bytes

(+ 12*4 bytes for the string *constants*)

`p[6]="july"` changes an address

(element 7 from pointer array `p`)

Indices or pointers: use sensibly

Declare index in `for` loop header whenever possible (since C99)

- enforces scope, visually clear, avoids affecting other loops

Do use indices if more suggestive, though combinations are possible

```
void matmul_i(unsigned m, unsigned n, unsigned p, double a[][n],
    double b[][p], double c[][p]) {
  for (int i = 0; i < m; ++i)
    for (int j = 0; j < p; ++j) {
      c[i][j] = 0;
      for (int k = 0; k < n; ++k) c[i][j] += a[i][k]*b[k][j];
    }
}
void matmul_p(unsigned m, unsigned n, unsigned p, double a[][n],
    double b[][p], double c[][p]) {
  double *lastl = a[m];
  for (double *lp = a[0], *dp = c[0]; lp < lastl; ++lp)
    for (int j = 0; j < p; ++j, ++dp) {
      *dp = 0;
      for (int k = 0; k < n; ++k) *dp += lp[k]*b[k][j];
    }
} // could you use more pointers ? For b perhaps ?
```

Type casts, `void *` and `typedef`

`void *` is used for addresses of any/unspecified type
⇒ *can't dereference* a `void *` (don't know what it points to)
but can assign to/from pointer of any other type
any pointer OK as arg/result for function declared with `void *`

Type cast is a unary *operator*, written as (*type-name*) *expression*
the value of *expression* is converted to the type *type-name*

convert int to real `(double)sum/cnt //force real division`
dereference a `void *` `*(char *)p //char at address p`

`typedef` is a keyword used to define a *new name* for type

Syntax: `typedef` *declaration* the identifier becomes a type *name*

```
typedef uint16_t u16; //u16 is synonym for type uint16_t
typedef char line[80]; //line: type for array of 80 chars
line text[100]; //text is array of 100 lines
```

Function pointers

A function *name* is its *address* (a pointer) – like for arrays
We can *declare* pointers of function type. Compare:

`int f(void);` declares a *function* returning int
`int (*p)(void);` declares *pointer to function* returning int

declare *function*: *restype* `fct` (*type1*, . . . , *typeN*) ;
declare *function pointer*: *restype* `(*pfct)` (*type1*, . . . , *typeN*) ;
Can assign `pfct = fct` with the name of an existing function

CAUTION! Need parantheses for `(*pointer)`, otherwise:
`int *fct(void);` is a function returning *pointer to int*
Function name is pointer ⇒ can call function using pointer

```
#include <math.h>
void printvals(double (*f)(double)) { // function parameter
  for (int i=0; i<10; ++i) printf("%f\n", f(.1*i));
}
int main(void) { printvals(sin); printvals(cos); return 0; }
```

Using function pointers

`stdlib.h`: binary search for key in sorted array; and quicksort

```
void *bsearch(const void *key, const void *base, size_t nmemb,
      size_t size, int (*compar)(const void *, const void *));
void qsort(void *base, size_t num, size_t size,
                    int (*compar)(const void *, const void *));
```

- address of array to sort, element count and size
- address of comparison function, returns `int` $<, =$ or > 0)
  - has `void *` arguments, compatible with pointers of any type

```
typedef int (*comp_t)(const void *, const void *); // cmp fun
int intcmp(int *p1, int *p2) { return *p1 - *p2; }
int tab[5] = { -6, 3, 2, -4, 0 }; // array to sort
qsort(tab, 5, sizeof(int), (comp_t)intcmp); // sort ascending
```

Can also declare function with `void *`, do cast in function

```
int intcmp(const void *p1, const void *p2)
      { return *(int *)p1 - *(int *)p2; }
qsort(tab, 5, sizeof(int), intcmp); // no cast, has right type
```

When to use pointers ?

When the language *forces* us to:
arrays (memory blocks) cannot be passed / returned from functions
  only their *address* (array name is its address)
addresses carry *no size* information ⇒ must pass size parameter

strings: a string (constant or not) is a `char *`
  need not pass size, since null-terminated

functions: a function name is its address

When a function needs to modify variable passed from outside
  pass *address* of variable

WARNING! Any address passed to a function needs to be valid (point to allocated memory)
  functions *use* their arguments ⇒ pointers must be valid