Computer Programming

User-defined types

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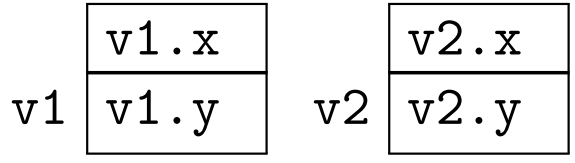
Structures are for compound values

group (logically connected) elements of potentially different types
can use/assign/pass/return entire compound value, or parts of it

```
struct len {  // type is 'struct len', 'len' = structure tag
  double val;
  char unit[3];
};              // a type for physical quantities
struct len d1 = { 60, "km" }; // declaration + initialization
```

```
struct vect { // type: 'struct vect'
  double x, y;
} v1, v2;   // two vars of this type
```



Structure elements are called *fields*
of any type, but *NOT* the *same* structure type (~~infinite recursion~~)

How to access/use fields: *var_name*.*field_name*
the dot `.` is the postfix *selection operator*

```
struct vect p1; p1.x=2; p1.y=3; printf("%f %f\n", p1.x, p1.y);
```

Allowed operations

We may write *compound structure values*, with/out field names:

```
struct vect v1 = { 2, 3 }, v2 = { .x = 4, .y = 5 };
```

We may *assign* structures: `struct vect v1={2, 3}, v2; v2=v1;`

Except for initialization, need (type cast) for aggregate values:

```
struct vect v3, v4;
v3 = (struct vect){-4, 5};
v4 = (struct vect){ .x = -1, .y = 2};
```

Structures may be *passed* to and *returned* from functions
for large structures should pass/return pointers (less copying)

```
struct vect add(struct vect v1, struct vect v2) {
  return (struct vect){ v1.x + v2.x, v1.y + v2.y };
}
```

We *may NOT compare* structures with logical operators (==, !=)
$\Rightarrow$ must compare field by field: `if (v1.x==v2.x && v1.y==v2.y)`...
Reason: *alignment* in memory may cause spaces between fields
value of these hidden bytes is undetermined $\Rightarrow$ don't use `memcmp`

Structures and arrays

In C, aggregated (compound) types may be combined arbitrarily
arrays of structures, structures with array or structure fields, etc.

Define types to *logically group data*

E.g. replace two related arrays of same range by array of structures:

```
char* name_mo[12] = { "January", /* ... , */ "December" };
char day_mo[12] = { 31, 28, 31, 30, /* ... , */ 30, 31 };
// better:
struct month {
  char *name;  // pointer to string constant
  int days;
};
struct month mo[12] = {{"January",31}, ..., {"December",31}};
```

Structures and typedef

`typedef` allows us to give new names to existing types

General form: `typedef` *existing-type new-type-name*;
(like variable declaration + `typedef` in front ⇒ names a *type*)

e.g. `typedef double real;` `typedef struct vect vect_t;`

```
typedef int (*cmpfun_t)(const void *, const void *);
```

We can give the name directly in the type definition

```
typedef struct student { /*some fields */} student_t;
```

may omit structure tag (after `struct`) and use just new name

```
typedef struct { /*some fields */} student_t;
```

or separately define synonym and structure type (in either order)

```
struct student { /*some fields */}; //defines type
typedef struct student student_t; //defines synonym
```

Structures and strings

```
typedef struct {
  char name[64];    // fixed-length array
  char *addr;       // only ADDRESS, NO memory for chars
} student_t;        // declares name for structure type
student_t s;
```

`s.name` is *array*: we can copy or read a string:
CANNOT assign ~~`s.name =`~~, it's a CONSTANT address!

```
strcpy(s.name, "Stefanovici"); //NOT s.name = ...
if (scanf("%63s", s.name) == 1) ...
```

`s.addr` is *pointer*: we must assign a *valid* address
e.g., a string constant: `s.addr = "str. Linistei 2";`
or dynamically allocated memory:

```
if (fgets(buf, sizeof(buf), stdin) s.addr = strdup(buf);
```

Field names are only visible *inside* the structure
$\Rightarrow$ cannot use fieldname by itself, only *varname*.*field*
$\Rightarrow$ different structure types can have fields with same name

Pointers to structures

Like any variable, a structure can be accessed through a pointer:

```
struct student s, *p = &s; (*p).final_grade = 9.50;
```

The `->` operator is shorthand for indirection followed by selection:
use: `pointer->fieldname` means: `(*pointer).fieldname`

Operators `.` and `->` have the *highest precedence*, like `()` and `[]`

`p->x++`	means	`(p->x)++`	`->` has priority
`++p->x`	means	`++(p->x)`	`->` has priority
`*p->x`	means	`*(p->x)`	`->` has priority
`*p->s++`	means	`*((p->s)++)`	first `++` then `*` (right assoc.)

Recursive data structures

A structure field may not be a structure of the *same type*
size of the structure would be undefined/infinite
But can have *address* of the same type of structure (a pointer)
$\Rightarrow$ *recursive, linked* datastructures (lists, trees, etc.)

```
struct wl {       // struct wl incompletely defined type at this
  char *word;     // word: the actual data
  struct wl *next; // pointer to same type of structure
};                // type definition is now complete
```

Binary tree with integer nodes

```
typedef struct t tree_t; // tree_t is name for incomplete type
struct t {
  int val;
  tree_t *left, *right; // use typedef name
};          // type struct t now complete, same as tree_t
```

Structures with bitfields

We usually want to represent information as compactly as possible but don't use too restrictive assumptions! (see Y2K problem)

date = 32-bit int: sec, min (0-59): 6 bits, hour (0-23), day (1-31): 5 bits, month (1-12): 4 bits, year (1970 + 0-63): 6 bits

```
struct date {  // structure with bitfields
  unsigned sec : 6, min : 6; // 6 indicates bit count
  unsigned hour : 5, day : 5; // each field must have width
  unsigned month: 4;  // use only integer types
  unsigned year: 6;
} data = {0, 0, 17, 19, 5, 39 }; // 17:00:00, 19.05.(1970+39)
```

We can directly write:

```
printf("%u.%u\n", data.day, data.month);
```

Nameless fields can control space used: `int: 2; //2 bits`
or force storing data starting in the next byte `int:  0;`

Structures and alignment

Compiler *aligns* each data type in memory for best processor access
can find out with `_Alignof` operator

```
printf("%zu %zu\n", _Alignof(int), _Alignof(char*)); //4 8
```

Structure fields are in order but need not be in consecutive bytes
`offsetof`(*structuretype*, *fieldname*) tells where (from `stddef.h`)

```
typedef struct { char s[3]; char val[8]; } s1_t;
typedef struct { char s[3]; double val; } s2_t;
printf("%zu %zu\n", offsetof(s1_t, val), sizeof(s1_t)); // 3 11
printf("%zu %zu\n", offsetof(s2_t, val), sizeof(s2_t)); // 8 16
// because _Alignof(double) is 8 bytes
```

Always check if your code relies on a specific alignment!
(e.g., to directly read an entire structure value from a file)

Structures with flexible array members

Sometimes the size of an array field is not known statically
⇒ *last* member of a structure may be an incompletely defined array

```
typedef struct {
  char *fname;
  unsigned argc;        // number of args
  int args[];           // default length is zero
} func_t;               // type for a function of integers
```

When declaring `func_t f;` the array has length 0 (no elements)

But, can dynamically create a structure of the desired size:

```
func_t *fp = malloc(sizeof(func_t) + n * sizeof(int));}
// or: ... + sizeof(int [n])
if (fp) {
  fp->argc = n;
  for (int i = 0; i < n; ++i)
    fp->args[i] = ...
}
```

Enumeration type

gives *names* to integer values (constants)
⇒ use when names are more suggestive than integers

```
enum univ_mo {jan=1, feb, mar, apr, may, jun, oct=10, nov, dec};
```

defines type `enum univ_mo` (the keyword is part of the type name)
Default: increasing sequence of values, starting at 0
Can explicitly specify values (restarts count); values may repeat

An enumeration type is an *integer* type ⇒ values used as ints

```
enum {Su, M, Tu, W, Th, F, Sa} day_t; // anonymous type
int work_hours[7];                    // per weekday
for (int day = M; day <= F; ++day) work_hours[day] = 8;
```

Enumeration constants are used by themselves (one namespace)
⇒ A constant name may *NOT* be used in distinct enumerations

Unions

Used to store a value which may have one of several *different* types

Syntax: as for structures, but with keyword `union`

List of fields is a *list of variants*

- a structure contains *all* declared fields
- a union contains *exactly one* variant; has size of *largest* type

```
struct ids {
  enum { INT, DBL, STR } type; // remembers which variant
  union {          // anonymous union type
    int i;
    double r;
    char *s;
  } u;
} v;           // three variants for a value
char s[32]; if (scanf("%31s", s) == 1) {
  if (isdigit(*s)) // starts with digit or contains dot
    if (strchr(s,'.')) { v.type=DBL; sscanf(s, "%lf", &v.u.r); }
    else { v.type = INT; sscanf(s, "%d", &v.u.i); }
  else v = (struct ids){ .type = STR, .u.s = strdup(s) };
}
```