Declarations

- Storage class specifiers

- Type specifiers

- Type qualifiers

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- Declarators

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- Initialization

```
int fun(int a, int b)
{
        static int initialized; /* zero. */
        if (!initialized) {
                init();
                initialized = 1;
        }
        /* do the normal work... */
}
```

- Used to make an identifier invisible outside the block (function in this case)
- Static storage duration: variable is not located on the stack but among global variables; preserves its value across function calls

```
int fun(int a, int b)
{
        static int c = 12;   // OK.
        static int* d = &c;  // OK.
        static int* e = &a;  // Invalid.
}
```

- A static variable can be initialized with a constant expression
- An address may or may not be constant: **&c** is a constant expression but **&a** is not.

Storage class specifiers: extern 1(2)

```
extern int a;                    // does not reserve storage for a.

int main()
{
        sizeof a;
        return 0;
}
```

- If the value of an extern identifier is used, storage must have been reserved for it somewhere in some file.

- In the program above, the value of a is not used so no definition is needed

Storage class specifiers: extern 2(2)

```
static int a;              // reserves storage for a.
extern int a;              // a still invisible outside the file.
extern int b;              // b is global visible outside the file
static int b;              // Undefined behavior. static follows extern.
int fun();                 // Implicitly external linkage.
int main() { fun(); }      // Use fun assuming it has external linkage.
static int fun() { }       // Undefined behavior.
```

- The extern does not change a previously declared visible storage class.

- static followed by extern is OK but extern followed by static is not.

- These rules have to do with how one-pass compilers can be implemented, assembler code may already have been generated which cannot be changed.

Storage class specifiers: auto and register

```
int fun()
{
        register int c;
        int*         d = &c;                    // invalid
        register int e[4]                       // OK.
        register struct { int a; int b; } f;    // OK.
}
```

- **auto** is completely useless (and does not mean the same as in C++)

- It is still in the C standard since changing the standard should not break existing C code

- **register** indicates to the compiler that the variable should be kept in a register if possible. usually ignored, except for semantic analysis: the address of a variable with register storage class cannot be taken

Storage class specifiers: typedef

```
typedef int int32_t;
typedef struct info_t info_t;
struct info_t {
        info_t*          next;
        int              data;
};
```

- **typedef** creates a synonym for a type.

- **typedef** is not really a storage class specifier. called so for syntactic convenience only.

- The type specifiers are: **void**, **char**, **short**, **int**, **long**, **float**, **double**, **signed**, **unsigned**, **_Bool**, **_Complex**, **_Imaginary**, *struct-or-union*, *enum-specifier*, and *typedef-name*.

- The type specifiers are combined into lists including **signed char**, **unsigned char**, **char**, **signed long long** and **long double**.

- Note that **signed char**, **unsigned char**, and **char** all are different types: **char** behaves like one of the other two (which is implementation-defined) but it is a distinct type.

```
char*            s;
unsigned char*   t = s; // invalid.
```

```
_Bool a;
#include <stdbool.h>
bool  b;
```

- The type **_Bool** was introduced in C99.
- **<stdbool.h>** defines **bool** as a macro which expands to **_Bool**.
- A bool can only take the values zero and one.
- An assignment to a bool variable stores a one if the expression is not zero.

Type specifiers: enum

```
enum colour { RED, BLUE, GREEN };
enum a { a, b = 100, c };
typedef enum { PORSCHE, MERCEDES, KOENIGSEGG } car_t;
car_t   car = PORSCHE;
```

- An enum declares named int constants

- Enums are "better" than #defines because debuggers understand them

- The *tags* **colour** and **a** are in a name space different from variables and enumeration constants.

- The variable **car** can be used where an int can be used, eg as an array index.

Type specifiers: structs and unions

```
struct s {
        int          a;                // OK.
        int          b:1;              // OK, but signedness impl. def.
        signed int   c:1;              // OK, one signed bit.
        unsigned int d:1;              // OK, one unsigned bit.
        _Bool        e:1;              // OK.
        car_t        f:2;              // OK if implementation permits.
        int          g(int, int);      // No, not in C.
        int          (*h)(int, int);   // OK. Pointer to function.
        int          i[0];             // No (but valid in GCC).
        int          j[];              // OK if last member in C99
};
```

- Avoid using plain int as bitfield type. Specify whether it is signed or not.

union

```
union u {
        char    a[9];
        double  b;
};
```

- Alignment: for example, a 4-byte int wants to have an address that is a multiple of 4
- What is the size of this union?

Flexible Array Member 1(3)

```
struct s {
        size_t              n;
        int*                a;
};

struct s*                   s;

s = xmalloc(sizeof(struct s));
s->n = n;
s->a = xmalloc(n * sizeof(int));
```

Flexible Array Member 2(3)

```
struct s {
        size_t              n;
        int                 a[1];
};

struct s*                   s;
size_t                      size;

size = sizeof(struct s) + (n-1) * sizeof(int);
s = xmalloc(size);

s->a[n-1] = 119; // Array index out of bounds => UB
                 // UB == undefined behavior
```

- Known in the C standard as the "struct hack".

- Everybody "knows" it works but tools may complain.

Flexible Array Member 3(3)

```
struct s {
        size_t          n;
        int             a[];    // Flexible array member
};

struct s*               s;
size_t                  size;

size = sizeof(struct s) + n * sizeof(int);
s = xmalloc(size);
s->a[n-1] = 119; // OK
```

- Avoids storage for the pointer and is valid since C99
- Flexible array member cannot be only attribute
- Flexible array member must be last!
- Therefore at most only one flexible array member!
- Only for heap allocated structs!

Type qualifiers

```
const int a = 12;   // OK.
const int* b = &a;  // OK.
*b = 13;            // invalid.
a = 14;             // invalid.
```

- **const** the variable cannot be changed after initialization.

- **volatile** the variable can be changed in "mysterious" ways: do not put it in a register.

- **restrict** a pointer parameter with restrict qualifier points to data which no other visible pointer can refer to. helps optimizer but can cause extremely obscure bugs if the programmer is not careful.

Volatile qualifier

```c
#include <signal.h>
volatile int x;
void catch_ctrl_c(int sig) // called when you hit CTRL-C.
{
        x = 0;
}

int main()     // below line will tell your computer to call the
{              // function catch_ctrl_c when you hit CTRL-C.
        signal(SIGINT, catch_ctrl_c);
        x = 1;
        while (x)  // when compiling with optimisation and without
                ; // volatile, GCC thinks X cannot change!
}
```

- The `const` qualifier informs the compiler it can put a variable in read-only memory. Only an initialisation is permitted.

- The `restrict` qualifier informs the compiler that two parameters can not point to the same memory area. This is new in C99 and its purpose is to tell the compiler some advanced tricks are legal.

```c
void f(restrict int* a, restrict int* b, int n)
{
        int     i;
        for (i = 1; i < n-1; i++)
                a[i] = 2 * b[i-1] + 3 * b[i] + 4 * b[i+1];
}
```

Declarators: Type constructors

- There are three type constructors:
  - Array
  - Function
  - Pointer

- Array and Function have higher precedence than Pointer

- Place array dimension or the function's parenthesis to the right of the declarator and a star before the declarator

- Confusion arises because the type cannot be read from left to right but must be read from "inside" to the "outside": **int (*a[12])(int);**. What is the type of **a**?

Declarators: Examples

```
int     a;          // int
int     *b;         // pointer to int
int     **c;        // pointer to pointer to int
int     d[4];       // array of int
int     e[4][5];    // array of array of int
int     *f[4];      // array of pointers
int     (*g[4])[5]; // array of pointers to array of int
int     *h();       // function returning pointer to int
int     (*i)();     // pointer to function returning int
int     *j()();     // NO: func returning func returning pointer to int
int     (*k())();   // func returning pointer to func returning int
```

- A function cannot return a function or an array, only pointers to them.

Initialization

```c
int     n = 10;

typedef struct { int a, b, c, d; } type_t;
int main()
{
        int       a[10] = { 1, 2 };    // rest will be set to zero.
        int       b[] = { 1, 2, 3 };   // sizeof b == 3 * sizeof(int)
        int       c[] = { [4] = 12 };  // c[0..3] == 0
        type_t    d = { .a = 3, .c = 5,6 }; // d.d == 6.
        int       e;                   // undefined value.
        static int f;                  // zero.
        typedef int array[];           // incomplete type array
        array     g = { 1, 2, };       // does not affect the type array.
        array     h = { 1, 2, 3 };     // OK: array still incomplete.
        int       i[n];                // undefined values
        int       j[n] = { 1, 2, 3 };  // no
}
```