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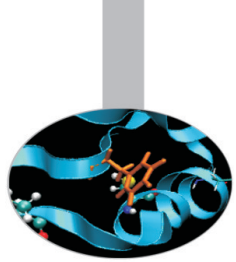

Scientific and Technical Computing in C

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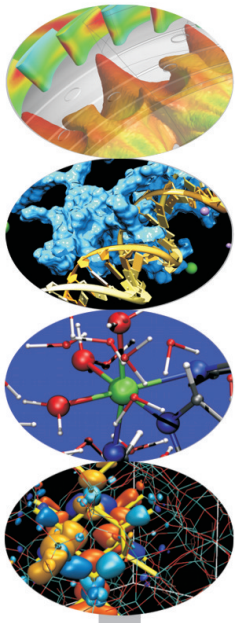

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Outline

You May Need More

- You may find yourself in need to return more than one result from a function
- And you may find yourself in need to pass a big `struct` to a function, without paying the price of copying its value
- And, believe it or not, in some part of your program you may find yourself in need to access a variable whose name is not known
- And to represent things as multiblock, unstructured grids, or building structures, or complex molecules, you may find yourself in need to access variables that don't even have a name

- In all these cases, you have to use memory addresses

Memory? Addresses?

- You can think of memory as a huge array of units of storage (usually 8 bits bytes)
  - The index in this array is termed *address*
- But how many bytes are needed to store a value?
  - It depends on value type and platform
- And it's even worse...
  - Not all locations are good for any value (at least performancewise)
  - Not all locations can be read/written
  - What are the starting and ending address?
  - The amount of memory seen by your program could vary during execution
  - You could have 'holes' in this ideal array
  - Or this ideal array could be made of separate, independent segments

Enter C Pointers

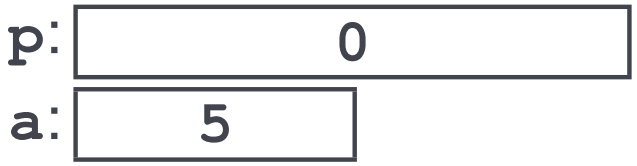
- Dealing directly with memory addresses is cumbersome
  - Easily makes the program non portable
  - Makes the program difficult to manage and confusing
  - Exhibits low level details you don't really want to care about
- How to avoid it?
- Named variables leave the whole issue to the compiler
  - You use the name and don't care about address
- C pointers let you manipulate addresses in a transparent and consistent way
  - They contain memory addresses
  - Allow you to manipulate addresses disregarding their actual values
  - Associate a C type to the memory location they point to
  - And give you a way to read or write this memory location, much like a named variable

Pointers Basics

- `int i, *p;`
  - declares an `int` variable `i`
  - and a 'pointer to `int`' variable `p`
  - in the latter, you can store the address of a memory location suitable to store an `int` type value
- `p = &i;`
  - `&i` evaluates to the address of variable `i`
  - `p` gets a valid address in
  - Got something familiar? Do you remember `scanf()`?
- `*p = 10;`
  - Expression `*p` is an *lvalue* of type `int`
  - You can performe assignment to it
  - You can use it in expressions to access the stored value
  - `*` has same precedence and associativity of unary `-`

Pointer vs. Pointee


```
int *p = NULL;
int a = 5;
```




```
p = &a;
```


```
*p += 10;
```


```
a += 1;
```

Avoiding Costly Copies


```
struct vect3D {
  double x, y, z;
};

// REMINDER: I have to make vcross() more efficient! DONE!!
struct vect3d vcross(const struct vect3D *u, const struct vect3D *v) {
  struct vect3D c;

  c.x = u->y*v->z - u->z*v->y;
  c.y = u->z*v->x - u->x*v->z;
  c.z = u->x*v->y - u->y*v->x;

  return c;
}
```

- Copying 6 **`doubles`** for very little work
- Let's put pointers to good use
- **`u->y`** is a convenient shorthand for **`(*u).y`**
- But now we have the address of the arguments and could make a mistake and change their contents
- Let's make the pointees **`const`**

Did we say “valid”?

- A valid pointer value is an address that:
  - is in the process memory space
  - points to something which exists
  - and whose type matches
- Invalid pointers
  - uninitialized pointers (point to the wrong place, at best)
  - the address of a variable that does not exist anymore
  - the address of one type put in pointer to another type (unless you REALLY know what you are doing)
  - a null pointer, i.e. a 0 address
- Dereferencing (with `*`) a null pointer forces runtime error
- Good practice:
  - Always initialize pointers
  - If you don’t know yet the right address, use **`NULL`** from **`stddef.h`**
  - `0` may also be used, but less readable

A Naive Mistake


```
struct vect3D {
  double x, y, z;
};

// REMINDER: I have to make vcross() more efficient! DONE!! Trying to do better...
struct vect3d *vcross(const struct vect3D *u, const struct vect3D *v) {
  struct vect3D c;

  c.x = u->y*v->z - u->z*v->y;
  c.y = u->z*v->x - u->x*v->z;
  c.z = u->x*v->y - u->y*v->x;

  return &c; // MADNESS!!
}
```

- Sparing another copy it's tempting...
- But it's very naive!
- `c` is an automatic variable, and it's gone when the pointer is used
- And probably the memory locations have been already reused and overwritten!

Returning More Than One Result


```
#include <math.h>

struct vect3D {
  double x, y, z;
};

struct vect3d versor_norm(const struct vect3D *u, double *norm) {
  struct vect3D c = {0.0, 0.0, 0.0};
  double n, invn;

  n = u->x*u->x + u->y*u->y + u->z*u->z;
  if (n == 0.0) {
    *norm = 0.0;
    return c;
  }

  n = sqrt(n);
  *norm = n;
  invn = 1.0/n;
  c.x = u->x*invn;
  c.y = u->y*invn;
  c.z = u->z*invn;
  return c;
}
```

- We have to return two results
- Of very different types and meanings
- Assembling them in a bigger **`struct`** makes little sense

Pointers and Arrays

- `double *p[10]`
  - it's an array of 10 pointers to `double`
- and `double *p[10][3]`
  - it's an array of 10 arrays, each of 3 pointers to `double`
- while `double (*p)[10]`
  - it's a pointer to array of 10 `double`s
- and `double (*p)[10][3]`
  - it's a pointer to an array of 10 arrays, each of 3 `double`s
- Confusing? It's logical: operator `[]` has higher precedence than `*`
- But easily becomes nasty!
  - What's `double (*p[10])[3]`?
  - And `double (*(*p[10])[3][5])[8][2]`?
- Best practice: use `cdecl` tool to familiarize and decrypt

Pointers Arithmetic

- Useful to poke around in arrays
- `p + 7`
  - will give you an address
  - that is `7*sizeof(*p)` after the one in `p`
- You can also use `-`, `+=`, `-=`, `++`, and `--`
- `p1 - p2`
  - if of the same pointer type, will give you an integer value
  - more precisely, of `ptrdiff_t` type (from `stddef.h`)
  - the displacement from `p2` to `p1` in units of `sizeof(*p1)`
- Pointer comparison
  - `==` (equal), `!=`, `>`, `<`, `>=`, `<=` can be used on pointers of the same type
- Pointer casting
  - Pointer values can be cast to pointers of different type
  - Do it VERY carefully, it's easy to do the wrong thing
  - Pointers may also be cast to some integer type, but it's highly non portable, don't do it

Pointers and Array Equivalence

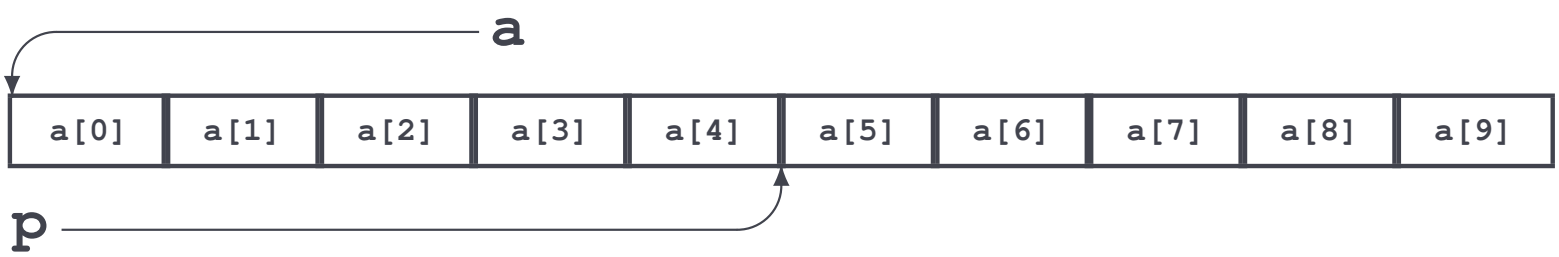
- `*(p+7)` can be shortened to `p[7]`
- Aha!
- Can a pointer be used as an array?
  - `true`
- I see... so is the array name a pointer?
  - `true`, but it's constant, you can't change it
- But if I have `int a[N]`, and `int *p`, may I assign `p=a`?
  - `true`, you can
- Then, what's the difference between an array variable and a pointer variable declarations?
  - An array declaration allocates memory for data
  - A pointer declaration allocates memory for a data address only
- And between array and pointer function parameters?
  - Irrelevant, an array argument passes a pointer
  - You are now ready to understand good old C tricks

Skeptical? Try to Believe

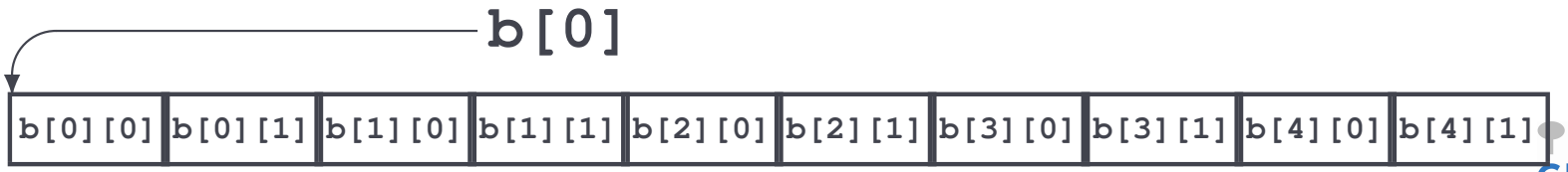

```
#include <stdio.h>

double a[] = {1.0, 2.0, 3.0, 4.0, 5.0};

int main() {

  double *p;

  p = a; // variable p now stores the address of array a

  printf("%lf\n", a[2]); // will print 3.0
  printf("%lf\n", *(p+2)); // will print 3.0

  p[2] = 7.0; // reassigns a[2]

  printf("%lf\n", p[2]); // will print 7.0
  printf("%lf\n", a[2]); // ditto, it's the same location

  return 0;
}
```

Array Names and Pointers


```
int a[10];
int *p = a + 5;
```




```
int b[5][2];
```



Averaging, with Pointers

- This one should be quite obvious
- Perfectly equivalent to using **`const double a[]`**
- You'll often encounter something like this, particularly in libraries

```
double avg(int n, const double *a) { /* which one is const? */
  int i;
  double sum = 0.0;

  for (i=0; i<n; ++i)
    sum += a[i];

  return sum/n;
}
```

`const int *p` is a pointer to **`const`**, **`int *(const p)`** is a **`const`** pointer

Calling `avg()`

- New or old style, array or pointer, simply pass array dimension and name
- And part of arrays could be managed too, independently of how it is written

```
double mydata[N];
double mydata_avg;
double firsthalf_avg, secondhalf_avg;

// read or compute N doubles into mydata[]

mydata_avg = avg(N, mydata);
firsthalf_avg = avg(N/2, mydata);
secondhalf_avg = avg(N - N/2, mydata + N/2);
```

Averaging Arrays, with Pointers

- Let's generalize to sets of *m* numbers
- And make it generic, as usual
- Now you are ready for the traditional solution
- And for an application of pointer casting

```
void avg(int n, int m, const double (*a)[], double *b) {
  int i, j;
  const double *p = (const double *)a;

  for (j=0; j<m; ++j)
    b[j] = 0;

  for (i=0; i<n; ++i)
    for (j=0; j<m; ++j)
      b[j] += p[i*m + j];     /* mapping two indexes */
                              /* to one `by hand' */
  for (j=0; j<m; ++j)
    b[j] /= n;
}
```

Calling Generic `avg()`

- New or old style, arrays or pointers, simply pass array dimension and name
- Using casts for arrays of doubles
- If `avg()` is written using VLAs, pedantic compilers may give a warning on function call, even if it's correct: they are wrong, check with Standard document or good book

```
double mydata1[N][12];
double mydata1_avg[12];
double mydata2[N][7];
double mydata2_avg[7];
double mydata3[N][1];
double mydata3_avg[1];
double mydata4[N];
double mydata4_avg;

// read or compute N 12-uples of doubles into mydata1[]
// read or compute N 7-uples of doubles into mydata2[]
// read or compute N 1-uples of doubles into mydata3[]
// read or compute N  doubles into mydata4[]

avg(N, 12, mydata1, mydata1_avg);
avg(N, 7, mydata2, mydata2_avg);
avg(N, 1, mydata3, mydata3_avg);
avg(N, 1, (double (*)[1])mydata4, &mydata4_avg);
```

Averaging Arrays, Another Classic Flavor

- Again averages sets of *m* numbers
- For arbitrary *m*
- This idiom arose when compilers were not good at optimization

```
void avg(int n, int m, const double (*a)[], double *b) {
  int i, j;
  const double *p = (const double *)a;

  for (j=0; j<m; ++j)
    b[j] = 0;

  for (i=0; i<n; ++i)
    for (j=0; j<m; ++j) {
      b[j] += *p;   /* array elements 'walked by' */
      ++p;          /* in the same sequence */
    }

  for (j=0; j<m; ++j)
    b[j] /= n;
}
```

Matrix Algebra, the Old Way

- Let's write a function to compute the trace of a matrix of **`double`**s
- And make it generic in the matrix size
- And use a traditional way
- Again, you'll often encounter something like this, particularly in libraries

```
double tr(int n, const double (*a)[]) {
  int i;
  double sum = 0.0;
  const double *p = *a;  /* works like casting here, why? */

  for (i=0; i<n; ++i)
    sum += p[i*n + i];

  return sum;
}
```

Matrix Algebra, Another Old Way

- Let's write a function to compute the trace of a matrix of **doubles**
- And make it generic in the matrix size
- And use another traditional way, from times when compilers didn't optimize well

```
double tr(int n, const double (*a)[]) {
  int i;
  double sum = 0.0;
  const double *p = *a;

  for (i=0; i<n; ++i) {
    sum += *p;
    p += n + 1;    /* next element on diagonal */
  }

  return sum;
}
```

Matrix Algebra, yet Another Classic Flavor

- Bottom line, we are working on **`doubles`**
- Call it like **`tr(8, (double *)mp)`**
- Or call it like **`tr(8, mp[0])`**
- Widely used in numerical libraries, but write new code using VLAs

```
double tr(int n, const double *a) {
  int i;
  double sum = 0.0;

  for (i=0; i<n; ++i) {
    sum += *a;
    a += n + 1; /* next element on diagonal */
  }

  return sum;
}
```

Matrix Algebra, a Bad Way

- A way of getting rid of all complexity
- It's the "third" use of type **`void`**
- Sometimes you'll find sloppy code like this
- But not a good idea in this case, it's dangerous

```
double tr(int n, const void *a) {
  int i;
  double sum = 0.0;
  double *p = a;

  for (i=0; i<n; ++i) {
    sum += *p;
    p += n + 1; /* next element on diagonal */
  }

  return sum;
}
```

`void` and Pointers

- `void *p;` declares a *generic pointer*
- I.e. a pointer pointing to unknown type
- If type is unknown, size is unknown
- So no arithmetic is possible, only assignment and comparisons
- The value of any pointer can be converted to a generic one
- A generic pointer can be converted to any pointer type

- So, what's the danger with `tr()`?
  - `tr()` assumes something pointing to `double`s
  - With `void *`, pointers at any type will do
  - A pedantic compiler would warn you at any use of `tr()`
  - And you'd get annoyed and switch off warnings
- But generic pointers are essential to other purposes

qsort()

- Declaration (from **stdlib.h**):

```
void qsort(
  void *base,
  size_t count,
  size_t size,
  int (*compare)(const void *el1, const void *el2) );
```

- Sorts an array of **count** elements of unknown type, starting at **base**
- Each element has size **size**
- What's **compare**?
  - **qsort()** doesn't know elements type
  - And has no clue at how to compare them
  - **compare** is a pointer to a function that knows more
- Yes, a function has an address and function name evaluates to it

Sorting with `qsort()`

- Define a comparison function like:

```
int comparedoubles(const double *a, const double *b) {
  if (*a == *b)
    return 0;

  if (*a > *b)
    return 1;

  return -1;
}
```

- Can you see how it matches the **`compare`** parameter?
- Then, if **`g`** is an array of 10000 **`doubles`**, you can sort it in ascending order like this:

```
qsort(g, 10000, sizeof(double), comparedoubles);
```

- Want it sorted in descending order?
  - Substitute < to >
- Have an array sorted in ascending order?
  - You can use **`bsearch()`** to find an element

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Outline

Characters

- In C, characters have type **`char`**
- I.e. an integer type holding the numeric character code
- But it's implementation defined if **`char`** is signed or not
- Encoding may depend on implementation and OS
- In most implementations, characters numbered 0 to 127 match the standard ASCII character set
- Literal character constants are specified like this: `'C'`
  - `'\n'` is new line
  - `'\t'` is tab
  - `'\r'` is carriage return
  - `'\\'` is backslash `\`
  - `'\''` is `'`
  - `'\"'` is `"`
  - and `'\0'` is ASCII NUL, with code 0, quite important despite of its value

#include <ctype.h>

Function	Returns
`int isalpha(int c)`	true if alphabetic character
`int isdigit(int c)`	true if a digit character
`int isalnum(int c)`	`isalpha(c) || isdigit(c)`
`int isprint(int c)`	true if printable character (including `' '`)
`int iscntrl(int c)`	`!isprint(c)`
`int islower(int c)`	true if lowercase alphabetic character
`int isupper(int c)`	true if uppercase alphabetic character
`int isspace(int c)`	true if `' '`, `'\t'`, `'\n'`, ...
`int tolower(int c)`	converts uppercase ones to lowercase others unchanged
`int toupper(int c)`	converts lowercase ones to uppercase others unchanged

- Do you remember? **`char`** types are converted to **`int`** in all arithmetic expressions
- Do not play with character codes, use these functions, they make the code portable

Strings

- Strings are not first-class citizens in C
- Simply arrays of **`chars`**
- The string must be terminated by a `'\0'` character
- Commonly referred to as *null terminated* strings
- This has annoying consequences
  - String lengths must be computed by scanning
  - No way for bounds checking
  - And a source of program weaknesses

- String constants are specified like this:
  `"A null terminated string"`
- A terminating `'\0'` is automatically appended
- You already met them using **`printf()`**
- Use a `\` at end of lines to write multiline string constants

The Biggest Mistake


```
char decdigits[10];

//...

strcpy(decdigits, "0123456789");
```

- The string is 10 characters long
- But it has a terminating `'\0'`
- So its internal representation is **11** characters long

Fixing the Biggest Mistake


```
char decdigits[] = "0123456789";
```

- An 11 characters array will be automatically allocated
- (Yes, you could do this for any array)
- But this only fixes the problem on initialization
- Not when you build string dynamically or do simple minded I/O
- Ever heard of '*buffer overflows*'?

Simple Computational Linguistics


```
// Frequencies of alphabetic characters in a text

#include <stdio.h>
#include <ctype.h>

#define LETTERS 26
#define CHUNK 256
unsigned counts[LETTERS];
char s[CHUNK+1];

int main() {
  int i;

  while ( fgets(s, sizeof(s), stdin) != NULL ) {
    char *p = s;

    while (*p) {
      if (isalpha(*p))
        ++counts[toupper(*p) - 'A'];
      ++p;
    }
  }

  for(i=0; i<LETTERS; ++i)
    printf("%c\t%9u\n", i + 'A', counts[i]);

  return 0;
}
```

Putting Characters and Strings to Work...

- We work on up to 256 characters at the time
  - But must accommodate for terminating `'\0'`
- `fgets()` is a robust I/O function
  - Reads from a file until end of line
  - Stores characters, including `'\n'`, into `s`
  - But no more than `sizeof(s)`-1
  - Null terminates the string
  - And returns NULL on end of input, or failure
- Loop terminates when `p` points to terminating `'\0'`

...Putting Characters and Strings to Work

- `char` is an integer type, we can do arithmetic on it
  - And alphabetic characters are coded in alphabetic order
- Remember: static variables are initialized to zero
- And some more I/O:
  - `%c`: emits a character from its code
  - `%9u`: prints a right-justified number in a field of width 9
  - `%s` is used for strings, as you'll see shortly
- Let's try it right now!
- Giving input from keyboard first, then from file...

charfreq.c


```
// Frequencies of alphabetic characters in a text

#include <stdio.h>
#include <ctype.h>

#define LETTERS 26
#define CHUNK 256
unsigned counts[LETTERS];
char s[CHUNK+1];

int main() {
  int i;

  while ( fgets(s, sizeof(s), stdin) != NULL ) {
    char *p = s;

    while (*p) {
      if (isalpha(*p))
        ++counts[toupper(*p) - 'A'];
      ++p;
    }
  }

  for(i=0; i<LETTERS; ++i)
    printf("%c\t%9u\n", i + 'A', counts[i]);

  return 0;
}
```

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#include <string.h>

Function	Does
`size_t strlen(const char *s)`	returns actual string length
`char *strncpy(char *d, const char *s, size_t n)`	copies `n` characters from `s` to `d`, returns `d`
`char *strncat(char *d, const char *s, size_t n)`	appends `n` characters from `s` to `d`, returns `d`
`int strcmp(const char *s1, const char *s2)`	lexicographic comparison of `s1` and `s2`
`int strncmp(const char *s1, const char *s2, size_t n)`	lexicographic comparison of `s1` and `s2`, up to `n` characters
`char *strchr(const char *s, int c)`	returns pointer to first occurrence in `s` of character `c`, `NULL` if not found
`char *strrchr(const char *s,) int c)`	returns pointer to last occurrence in `s` of character `c`, `NULL` if not found
`char *strcspn(const char *s, const char *set)`	returns pointer to first occurrence in `s` of any character in `set`, `NULL` if not found
`char *strspn(const char *s, const char *set)`	returns pointer to first occurrence in `s` of any character not in `set`, `NULL` if not found
`char *strstr(const char *s, const char *sub)`	returns pointer to first occurrence in `s` of string `sub`, `NULL` if not found
`char *strtok(const char *s, const char *set)`	allow to separate string `s` into tokens, read documentation

- Do you remember? **`char`** types are converted to **`int`** in many cases
- You'll also find in use **`strcpy()`** and **`strcat()`**: dangerous! avoid them
- Way too common mistake: forgetting about and writing code doing the same
- Don't reinvent the wheel, use library functions!

More Friends from `stdlib.h`

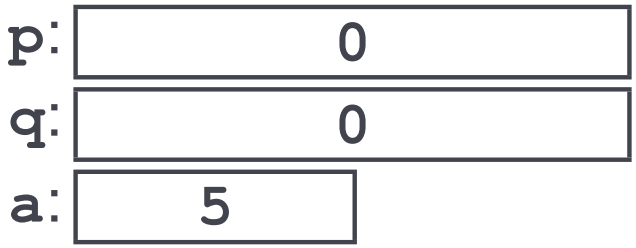
Function	Returns conversion of initial portion of `s` to
`strtof(const char *s, char **p)`[3]	`float`[1]
`strtod(const char *s, char **p)`	`double`[1]
`atof(const char *s)`	`double`
`strtold(const char *s, char **p)`[3]	`long double`[1]
`atoi(const char *s)`	`int`
`strtol(const char *s, char **p, int base`[2]`)`	`long`[1]
`atol(const char *s)`	`long`
`strtoul(const char *s, char **p, int base`[2]`)`	`unsigned long`[1]
`strtoll(const char *s, char **p, int base`[2]`)`[3]	`long long`[1]
`atoll(const char *s)`[3]	`long long`
`strtoull(const char *s, char **p, int base`[2]`)`[3]	`unsigned long long`[1]

1. If `p` is not null, sets it to point to first character after converted portion of `s`
2. The `base` used in string representation ranges from 2 to 36 (!).
3. C99

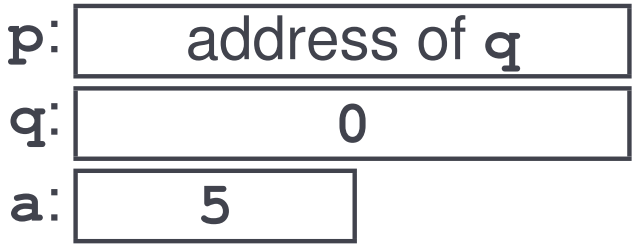
- More practical than `scanf()` family in many cases
- `strto...()` form preferred
- Use `sprintf()` to convert the other way around
- Where `char **p` appears, pass the address of a `char *` pointer variable...

Yes, Pointers can be Pointees!

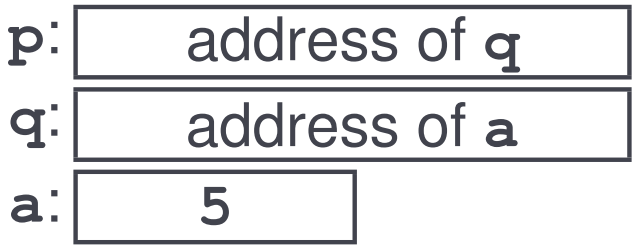

```
int **p = NULL;
int *q = NULL;
int a = 5;
```



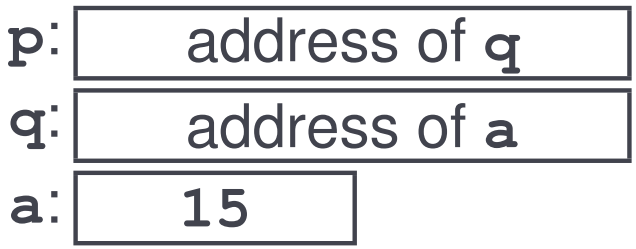

```
p = &q;
```




```
*p = &a;
```




```
**p += 10;
```



Time for Improvement

- Our program to compute characters frequencies in texts was appreciated and we got request for improvements
  - It's the price of success with software
- Some folks dislike uppercase output and want it lowercase
- Some folks disregard frequencies lower than some threshold
- Some more folks do not want zero frequencies to be output at all
  - Actually a restricted form of the previous request
- And some folks want the text to be read by a user specified file

- To accommodate their requests, let's refactor first

Computational Linguistics Refactored


```
// Frequencies of alphabetic characters in a text
#include <stdio.h>
#include <ctype.h>
#include <stdlib.h>
#define LETTERS 26
#define CHUNK 256
unsigned counts[LETTERS];
char s[CHUNK+1];
char *filename = NULL;  // will point to filename command line argument, if any
char outcase = 'A';     // change to 'a' for lowercase output
int minoutcount = 0;    // minimum frequency suitable for output

void parsecmdln(int n, char *args[]) { /* add command line processing here */ }

int main(int argc, char *argv[]) {
  int i;
  parsecmdln(argc, argv);

  while ( fgets(s, sizeof(s), stdin) != NULL ) {
    char c, *p = s;

    while ((c = *p++))
      if (isalpha(c))
        ++counts[toupper(c) - 'A'];
  }
  for(i=0; i<LETTERS; ++i)
    if (counts[i] >= minoutcount)
      printf("%c\t%9u\n", i + outcase, counts[i]);
  return 0;
}
```

`argc` and `argv`

- Up to now, we disregarded `main()` parameters
  - Which is legal
  - And writing `int main(void)` is legal too
- In its full glory, `main(int argc, char *argv[])` receives two arguments
  - An integer count, `argc`
  - And an array of `argc` pointers to string, `argv`
  - Names are not mandatory, just a solid tradition
- On most systems
  - `argv[0]` contains the name of program executable
  - `argv[1]` through `argv[argc-1]` contain the command line parameters specified at program invocation
- Form `int main(int argc, char **argv)` is fully equivalent
- `stdlib.h` needed later to parse threshold

charfreq.c Refactored


```
// Frequencies of alphabetic characters in a text
#include <stdio.h>
#include <ctype.h>
#include <stdlib.h>
#define LETTERS 26
#define CHUNK 256
unsigned counts[LETTERS];
char s[CHUNK+1];
char *filename = NULL;  // will point to filename command line argument, if any
char outcase = 'A';     // change to 'a' for lowercase output
int minoutcount = 0;    // minimum frequency suitable for output

void parsecmdln(int n, char *args[]) { /* add command line processing here */ }

int main(int argc, char *argv[]) {
  int i;
  parsecmdln(argc, argv);

  while ( fgets(s, sizeof(s), stdin) != NULL ) {
    char c, *p = s;

    while ((c = *p++))
      if (isalpha(c))
        ++counts[toupper(c) - 'A'];
  }
  for(i=0; i<LETTERS; ++i)
    if (counts[i] >= minoutcount)
      printf("%c\t%9u\n", i + outcase, counts[i]);
  return 0;
}
```

Our Options

- `-l` will force lowercase output
- `-t` ***`n`*** will set a minimum threshold for output
- An optional ***`filename`*** will specify a file to read from
- Let's add before `parsecmdln()` a function to call in response to `-h`
- And an helper function to manage user mistakes

```
void printUsage(void) {
  printf("charfreq [options] [filename]\n");
  printf("filename      input text (default: stdin)\n");
  printf("Options:\n");
  printf("-t n          frequency threshold\n");
  printf("-l            lowercase output\n");
  printf("-h            this help\n");
}

void illegalopt(const char *o) {
      fprintf(stderr, "illegal option: %s\n", o);
      printUsage();
      exit(EXIT_FAILURE);
}
```

Command Line Parsing


```
void parsecmdln(int n, char *args[]) {
  int i = 0;

  while (++i < n) {
    char *p = NULL;
    long th;

    if (args[i][0] != '-') {
      filename = args[i];      // must be filename
      break;                   // ignore anything following
    }

    switch (args[i][1]) {
      case 'l':
        outcase = 'a';
        break;
      case 't':
        th = strtol(args[++i], &p, 10);  // numeric argument follows
        if (p == args[i] || th < 0) {
          fprintf(stderr, "invalid or negative threshold\n");
          exit(EXIT_FAILURE);
        }
        minoutcount = th;
        break;
      case 'h':
        printUsage();
        exit(0);
        break;
      default:
        illegalopt(args[i]);
    }
  }
}
```

More Alternatives with `switch ()`

- **`switch`** (*integer-expression*) **`{`**
  `case` *constant-expression*`:`
  statements
  [**`case`** *constant-expression*`:`
  statements]
  [**`default:`**
  statements]
  `}`

1. Evaluates *integer-expression*
2. If value equals one *constant-expression*, execution jumps to the statement following it
3. Otherwise, if **`default:`** exists, execution jumps to statement following it
4. Otherwise execution leaves **`switch()`** and proceeds to the following code

A `switch ()` 'Feature'

- Beware: once 2 or 3 above happened, encounter of another **`case`** or of **`default`** does not imply exit from **`switch`**!
- A **`break;`** statement is needed to this purpose

- This is way too easily forgotten
- Best practices:
  - Always add a **`break;`** statement at end of each '**`case`**'
  - Even if it's unreachable, you'll appreciate on code changes
  - Unless you really intend to execute two or more '**`case`**s' at once

More `break`, and `continue`

- A `break;` statement forces execution to bail out from innermost enclosing statement among:
  - `switch ()`
  - `while ()`
  - `do...while ()`
  - `for (;;)`
- A `continue;` statement terminates execution of current iteration of innermost enclosing statement among:
  - `while ()`
  - `do...while ()`
  - `for (;;)`
- Execution continues with next iteration

On to Testing

- Let's try it right now!
- Does it work? Good!
- This approach is portable
  - But on UNIXes you'd have a better life using `getopt()`
- Now we have to implement input from ***`filename`*** file

Let's add it to `charfreq.c`


```
void parsecmdln(int n, char *args[]) {
  int i = 0;

  while (++i < n) {
    char *p = NULL;
    long th;

    if (args[i][0] != '-') {
      filename = args[i];      // must be filename
      break;                   // ignore anything following
    }

    switch (args[i][1]) {
      case 'l':
        outcase = 'a';
        break;
      case 't':
        th = strtol(args[++i], &p, 10);  // numeric argument follows
        if (p == args[i] || th < 0) {
          fprintf(stderr, "invalid or negative threshold\n");
          exit(EXIT_FAILURE);
        }
        minoutcount = th;
        break;
      case 'h':
        printUsage();
        exit(0);
        break;
      default:
        illegalopt(args[i]);
    }
  }
}
```

CINECA SCAI
SuperComputing Applications and Innovation

Scientific and Technical Computing in C

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Rome, 3rd-5th May 2017

CINECA SCAI
SuperComputing Applications and Innovation

CINECA

Outline

Files

- C thinks of files as *streams* of data you can read/write from/to
- C has no notion of file content or structure: user knows about
  - You read what you know is there
  - You write what you want to put there
- Files are managed by internal data structures of **`FILE`** type
  - Whose details may be implementation defined
- All functions are declared in **`stdio.h`**
- Most functions return or accept pointers to **`FILE`** structures
- You simply declare variables of **`FILE *`** type and use these functions
  - And usually may disregard details

Three Files for Free

- When `main()` is called, three files have already been opened for you
- Accessible by three expressions of `FILE *` type
  - `stdin` for standard input
  - `stdout` for standard output
  - `stderr` for error messages output
- Usually map to user's terminal, unless they were redirected at command launch

Using More Files is not Free

- If `myfile` is a `FILE *` variable, open a file using:
  `myfile = fopen("mydata.dat", "r");`
- Second string is a mode:
  - `"r"` to read existing text file
  - `"w"` to create a new text file or truncate existing one to zero length
  - `"a"` to create a new text file or append to existing one
  - Use `"rb"`, `"wb"`, or `"ab"` for binary files
  - `"r+"` and `"r+b"` to both read and write to existing file
- Biggest mistake: assuming `fopen()` succeeded
  - `fopen()` returns NULL on failure
  - Always check and use `errno` to know more
- `fclose(FILE *f)` orderly closes an open file, do it when you are done with it
- A string `FILENAME_MAX` long is big enough for any file name

Simple String I/O

- **`char *fgets(char *s, int n, FILE *stream)`**
  - Reads in at most one less than **`n`** characters from stream and stores them into the buffer pointed to by s. Reading stops after an EOF or a newline.
  - Returns **`s`** on success, **`NULL`** on failure
  - A robust I/O function. Use it in your code.
- Use **`int feof(FILE *stream)`** to check if **`NULL`** was returned because end of file was reached
- **`char *fputs(const char *s, FILE *stream)`**
  - Writes **`s`** string to file
  - Returns **`EOF`** on error
- **`char *puts(const char *s)`**
  - Like **`fputs()`** on **`stdout`**, but adds a **`'\n'`**

- You'll encounter **`gets()`** in codes: offers no control on maximum input size, don't use it

Talking to Humans

- **`fprintf()`** converts internal formats of basic data types to human readable formats
- **`fprintf(`*`file, "control string", arguments`*`)`**
  - Characters in ***`control string`*** are emitted verbatim
  - But conversion specifications beginning with `%` cause the conversions and output of arguments
  - Arguments (i.e. expressions) must match conversion specifications in number, types, and positions
  - Conversion specification `%%` emits a `%` character and consumes no arguments
- **`printf()`** outputs to **`stdout`**
- **`snprintf()`** and **`sprintf()`**
  - Write to string instead of file
  - **`snprintf()`** is preferable as maximum string length can be specified

Common Mistakes

- Beware: if you want to remove item `c` from output in

  ```
  printf("Parameters: %lf, %lf, %lf\n", a, b, c);
  ```

  the following is not enough:

  ```
  printf("Parameters: %lf, %lf, %lf\n", a, b);
  ```

  you need to update the format string too:

  ```
  printf("Parameters: %lf, %lf\n", a, b);
  ```

- And on adding an item you have to add a proper conversion specifier
- Ditto for type mismatches: no argument checking is required
- In some cases, dire consequences could follow

- A clever compiler may be able to warn you, if you ask

`printf()`: Integer Types

- In `%d` and `%u`, `d` and `u` are conversions
  - Internal to base 10 text representation
- `l`, `ll`, `h`, and `hh`, are size modifiers
  - Look back at integer types table if you need a refresh
- Variations on a theme
  - `%10d`: at least 10 characters, right justified, space padded
  - `%.4d`: at least 4 digits, right justified
  - `%010d`: at least 10 characters, right justified, leading `0`s
  - `%-10d`: at least 10 characters, left justified, space padded
  - `%+d`: sign is always printed (not relevant for `u`)
  - `% d`: same, but a space if positive (not relevant for `u`)
- `printf("%-5d%+6.4d", 12, 12);`
  Prints?

`printf()`: Floating Types

- Conversions
  - `%f`: `float` to base 10 decimal text
  - `%E`: `float` to base 10 exponential text
  - `%G`: most suitable of the above ones
- `l` and `L` are size modifiers
  - Look back at floating types table if you need a refresh
- Variations on a theme
  - `%10f`: at least 10 characters, right justified, space padded
  - `%.4f`: 4 digits after decimal point (`f` and `E` only)
  - `%.7G`: 7 significant digits
  - `%010f`: at least 10 characters, right justified, leading `0`s
  - `%-10f`: at least 10 characters, left justified, space padded
  - `%+f`: sign is always printed
  - `% f`: same, but a space if positive
- `printf("%+8.2lf %.4lE", 12.0, 12.0);`
  Prints?

`printf()`: Characters and Strings

- `%c`: emits character with specified code
- No variations

- `%s`: emits a string
- Variations on a theme
  - `%10s`: at least 10 characters, right justified, space padded
  - `%.7s`: exactly(!) 7 characters from string
  - `%-10s`: at least 10 characters, left justified, space padded
- `printf("%-7s%4.3s", "Vigna", "Vigna");`
  Prints?

- And more conversions are defined, but we'll not cover them

Listening to Humans

- **`fscanf()`** converts human writable formats of basic data types to internal ones
- **`fscanf(`*`file, "control string", arguments`*`)`**
  - Arguments must be pointers!
  - Arguments must match conversion specifications in number, types, and positions
  - White-space in ***`control string`*** matches an arbitrary sequence of zero or more spaces
  - All other characters must match verbatim with characters in input
- **`scanf()`** reads from **`stdin`**
- **`sscanf()`** reads from string instead of file

`scanf()` Conversions

- Conversions discussed for `printf()` work, the other way around
- They skip white-space characters before reading and converting, except for `%c`
- Number too big for the type? Result is implementation defined
- Fewer variations on the theme (for most conversions)
  - `%10d`: no more than 10 characters considered (not for `%c`)
  - `%*d`: looks for text matching an `int`, but ignores it
- `scanf("%4d%*6d%3d", &i1, &i2);`
  Input: `12  34567890` (notice: 3 space characters)
  Reads?

Common Mistakes

- Any mismatch in input to a **`scanf()`** will stop input and conversions
- **`scanf()`** always returns the number of conversions performed, do not discard it:

  ```
  itemsread = scanf("%lf ,%lf", &a, &b);
  ```

  check the result, and take correcting actions (or fail gracefully)
- Giving fewer arguments than conversion specifiers, as in:

  ```
  itemsread = scanf("%lf ,%lf ,%lf", &a, &b);
  ```

  is a very good recipe for disaster, and one difficult to debug
- So is giving the wrong pointer or a pointer to the wrong type

User Input


```
//...
    printf("Enter t max: ");
    scanf("%lf", &tmax);
```

- User mistypes `U.0` for `7.0`
- Program behaves in unintended ways
- Could check **`scanf()`** return value and fail gracefully, but let's give user a chance

Wrong Solution


```
  int itemsread;
//...
  do {

    printf("Enter t max: ");

    itemsread = scanf("%lf", &tmax);

  } while (itemsread == 0);
```

- Again, user mistypes `U.0` for `7.0`
- Program stops responding, burning CPU cycles
- `scanf()` is very finicky about input
  - As soon as a character doesn't match the format string, puts it back in input buffer
  - To find it again at each iteration

Better Solution


```
  int itemsread;
//...
  do {
    char s[257];

    printf("Enter t max: ");
    if (fgets(s, sizeof(s), stdin) == NULL)
      exit(EXIT_FAILURE);

    itemsread = sscanf(s, "%lf", &tmax);

  } while (itemsread == 0);
```

- This form causes wrong input to be consumed and removed
- Use **`fscanf()`** for rigidly formatted files
- With imprecise formats (as user input is), use **`fgets()`**, then **`sscanf()`**

Ready for Release 2.0


```
// includes, defines, variable declarations, and function definitions unchanged

int main(int argc, char *argv[]) {
  int i;
  FILE *textfile = stdin;

  parsecmdln(argc, argv);

  if (filename != NULL) {
    textfile = fopen(filename, "r");
    if (!textfile) {
      perror(filename);
      exit(EXIT_FAILURE);
    }
  }

  while ( fgets(s, sizeof(s), textfile) != NULL ) {
    char c, *p = s;

    while ((c=*p++))
      if (isalpha(c))
        ++counts[toupper(c) - 'A'];
  }

  if (filename != NULL)
    fclose(textfile);

  for(i=0; i<LETTERS; ++i)
    if (counts[i] >= minoutcount)
      printf("%c\t%9u\n", i + outcase, counts[i]);

  return 0;
}
```

That's It

- `fgets()` is passed `textfile`, initialized to `stdin` `FILE` pointer
- If no filename was provided on command line, `filename` will still be `NULL`
  - Business as usual
- Otherwise, `filename` will point to filename command line argument string
  - Let's open it
  - Let's fail orderly, if `fopen()` failed
  - Let's close file as soon as we are done with it
- Let's try it right now!

charfreq.c Release 2.0


```
// includes, defines, variable declarations, and function definitions unchanged

int main(int argc, char *argv[]) {
  int i;
  FILE *textfile = stdin;

  parsecmdln(argc, argv);

  if (filename != NULL) {
    textfile = fopen(filename, "r");
    if (!textfile) {
      perror(filename);
      exit(EXIT_FAILURE);
    }
  }

  while ( fgets(s, sizeof(s), textfile) != NULL ) {
    char c, *p = s;

    while ((c=*p++))
      if (isalpha(c))
        ++counts[toupper(c) - 'A'];
  }

  if (filename != NULL)
    fclose(textfile);

  for(i=0; i<LETTERS; ++i)
    if (counts[i] >= minoutcount)
      printf("%c\t%9u\n", i + outcase, counts[i]);

  return 0;
}
```

Dealing with Many Data

- Text I/O is human readable
- Text I/O is platform independent
- But text I/O is huge
  - Because of issues in base 2 vs. base 10 representation
- To recover exact binary form of a floating type, you need:
  - at least 9 decimal digits in text I/O for a **`float`**
  - at least 19 decimal digits in text I/O for a **`double`**
- And text I/O is slow
  - Because of size
  - And because conversions take time
- Best practice:
  - Use text I/O to talk to humans or as a last resort for some programs
  - Use binary I/O otherwise

Binary Reads and Writes


```
size_t fread(void *data, size_t elsz,
                         size_t count, FILE *f);
size_t fwrite(const void *data, size_t elsz,
                         size_t count, FILE *f);
```

- Read/write ***count*** elements of size ***elsz*** from/to file ***f*** to/from address ***data***
- Both return the number of elements actually read/written
  - Can be less than requested if error occurred, or (**fread()** only) end of file was encountered
  - Use **feof()** or **ferror()** to determine cause
- Best practice:
  - do binary I/O in chunks as large as possible
  - performance will sky-rocket

Walking Around in a File

- Each I/O operation takes place from the position in the file where the last one ended
- But position can be changed
- Not special to binary files, but mostly used with them
- **`fseek(f, 4096L, wherefrom)`** moves forward by 4096 bytes relative to:
  - file beginning, if ***`wherefrom`*** is **`SEEK_SET`**
  - current position, if ***`wherefrom`*** is **`SEEK_CUR`**
  - file end, if ***`wherefrom`*** is **`SEEK_END`**
  - and returns zero if successful, non zero otherwise
- **`ftell(f)`** returns the current position (**`long`**)
  - on failure, returns -1L and sets **`errno`**
- This is a 64 bits world: files can be huge!
  - In case, use **`fsetpos()`** and **`fgetpos()`**
  - They use an **`fpos_t`** type large enough

Dealing with Fortran Binary Files

- You may need to read Fortran binary files
- And Fortran adds two extra 32 or 64 bits integers, one at beginning and one at end of each record (i.e. of each **`WRITE`** for unformatted files)
- Option 1: skip them with **`fseek()`**
- Option 2: read them and forget the values
- Option 3: write the file from Fortran opening it in **`STREAM`** mode
  - Designed to match the C file concept
  - Introduced in Fortran 2003
  - But already available in most implementations

Scientific and Technical Computing in C

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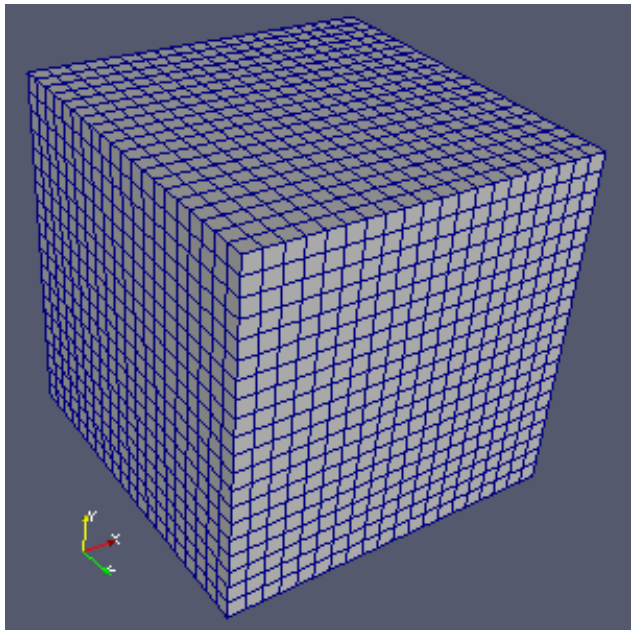
Rome, 3rd-5th May 2017

Outline

A PDE Problem



- Let's imagine we have to solve a PDE
- On a dense, Cartesian, uniform grid
  - Mesh axes are parallel to coordinate ones
  - Steps along each direction have the same size
  - And we have some discretization schemes in time and space to solve for variables at each point

A Rigid Solution


```
#define NX 200
#define NY 450
#define NZ 320

double deltax; // Grid steps
double deltay;
double deltaz;
//...
double u[NX][NY][NZ]; // x velocity component
double v[NX][NY][NZ]; // y velocity component
double w[NX][NY][NZ]; // z velocity component
double p[NX][NY][NZ]; // pressure
```

- We could write something like that at file scope
- But it has annoying consequences
  - Recompile each time grid resolution changes
  - A slow process, for big programs
  - And error prone, as we may forget about
- Couldn’t we size data structures according to user input?

Looking for Flexibility


```
int main(int argc, char *argv[]) {
  double deltax, deltay, deltaz; // Grid steps
  int nx, ny, nz
//...
  double u[nx][ny][nz];
  double v[nx][ny][nz];
  double w[nx][ny][nz];
  double p[nx][ny][nz];
```

- We could think of declaring variable length arrays inside **`main()`** or other functions
- This is unwise
  - Automatic arrays are usually allocated on the process stack
  - Which is a precious resource
  - And limited in most system configurations

A Better Approach


```
#define MAX_NX 400
#define MAX_NY 400
#define MAX_NZ 400

double u[MAX_NX*MAX_NY*MAX_NZ];
double v[MAX_NX*MAX_NY*MAX_NZ];
double w[MAX_NX*MAX_NY*MAX_NZ];
double p[MAX_NX*MAX_NY*MAX_NZ];

void my_pde_solver(int nx, int ny, int nz,
                   double u[nx][ny][nz],
                   double v[nx][ny][nz],
                   double w[nx][ny][nz],
                   double p[nx][ny][nz]);
```

- We could use VLA parameters
- But we should cast on calls, to avoid compiler warnings
  - How would you cast `u[MAX_NX*MAX_NY*MAX_NZ]` into `double u[nx][ny][nz]`?
- Maximum problem size is program limited: `nx*ny*nz` must be at most equal to `MAX_NX*MAX_NY*MAX_NZ`

Slightly More Comfortable, the Old Way


```
void my_pde_solver(int nx, int ny, int nz,
                   double u[],
                   double v[],
                   double w[],
                   double p[]) {
  // variable declarations and solver code...

  u[(i*ny + j)*nz + k] = ...;
  v[(i*ny + j)*nz + k] = ...;
  w[(i*ny + j)*nz + k] = ...;
  p[(i*ny + j)*nz + k] = ...;

  // more solver code...
```

- We could write code as the above, no need for casting on **`my_pde_solver()`** calls
- And you'll encounter code like this, that was a C89 way
- But so old fashioned!! Don't do that for new codes
- And remember, maximum problem size is limited

More Comfortable, Thanks to C99


```
void my_pde_solver(int nx, int ny, int nz,
                   double um[],
                   double vm[],
                   double wm[],
                   double pm[]) {

  double (*u)[ny][nz] = (double (*)[ny][nz])um;
  double (*v)[ny][nz] = (double (*)[ny][nz])vm;
  double (*w)[ny][nz] = (double (*)[ny][nz])wm;
  double (*p)[ny][nz] = (double (*)[ny][nz])pm;

  // solver code using u, v, w, and p as humans do
```

- Let's rewrite **`my_pde_solver()`** like this (and update function declaration as well!)
- Definitely easier to use
  - No casting on **`my_pde_solver()`** calls
  - And writing **`my_pde_solver()`** is easier too
- Maximum problem size still program limited, however

Removing Limitations

- Being program limited is annoying
- It's much better to accommodate to any user specified problem size
  - Right, as long as there is enough memory
  - But if memory is not enough, not our fault
  - It's computer or user's fault
- And there are many complex kinds of computations
  - Those in which memory need cannot be foreseen in advance
  - Those in which arrays do not fit
  - Those in which very complex data structures are needed

Enter Dynamic Allocation (from **`stdlib.h`**)


```
void *malloc(size_t size)
void *calloc(size_t el_count, size_t el_size)
```

- **`malloc()`** allocates a memory area suitable to host a variable whose size is **`size`**
  - Allocated memory is uninitialized.
  - Use it like this:

    ```
    a_ion_ptr = (ion *)malloc(sizeof(ion));
    ```

- **`calloc()`** allocates a memory area suitable to host an array of **`count`** elements, each of size **`size`**
  - Allocated memory is initialized to zero: can be slow, but useful
  - Use it like this:

    ```
    a_flt_ptr = (float *)calloc(nx*ny*nz, sizeof(float));
    ```

- Best practice: always cast return values, gives less compiler warnings and helps readability

The Biggest Mistake

- Assuming **`malloc()`** or **`calloc()`** succeeded!
- Where all these 'dynamic allocated memory' comes from?
  - From an internal area, often termed "*memory heap*"
  - When that is exhausted, OS is asked to give the process more memory
  - And if OS is short of memory, or some configuration limit is exhausted...
- On failure, **`malloc()`** and **`calloc()`** return null pointers
  - Dereferencing it forces program termination (usually a "segmentation fault")
  - We could say you deserve it
  - But all time spent in previous computations would be lost
- Best practice: ALWAYS, ALWAYS, always check

```
if ((p = malloc(some_size)) == NULL) {
   // save your precious data, if any
   // and fail gracefully
 }
```

Resizing


```
void *realloc(void *ptr, size_t new_size)
```

- **`realloc()`** takes a previously allocated memory area, and gives you a new area whose size is **`size`**
  - Original area contents are copied in the new area, up to min(*oldsize*, **`size`**)
  - Use it like this:

```
new_ptr = (float *)realloc(a_flt_ptr,
                           nx*ny*2*nz*sizeof(float));
```

- Particularly handy to shrink or lengthen arrays
- On failure, returns null pointer and leaves old area unchanged
- Biggest mistakes
  - Assuming **`realloc()`** succeeded: always check
  - Assuming only size changes and address remains the same: it can happen, but only in particular cases

Getting Rid of Memory Areas


```
void free(void *ptr)
```

- An allocated memory area persists until it is “freed”
- Of course, heap allocated memory is claimed back at process termination
- But better give back a memory area to the dynamic memory “pool” for reuse, as soon as you are over with it
  - Just imagine you are processing one item at a time...
  - Allocating new memory areas at each item without freeing previously allocated ones...
  - Your process size will grow until...
  - In jargon, this is a *memory leak*
- Remember: programmers causing memory leaks have particularly bad reputation

The First Big Mistake with `free()`


```
  char s[BIG_STRING + 1];
  char *p;
//....
  if ((p = malloc(BIG_STRING + 1)) == NULL) {
    // save your precious data, if any
    // and fail gracefully
  }
  strncpy(p, s, BIG_STRING);

  while (++p) {
    // process characters
  }
  free(p);  // p has been incremented!
  free(s);  // MADNESS: s not 'malloced'!
```

- `free()` MUST be passed a pointer returned by `malloc()` and friends
- Otherwise behavior is implementation defined
- In most practical cases, program execution is aborted

The Second Big Mistake with `free()`


```
int *p, i;
long long *q;

if ((p = malloc(sizeof(int)*n)) == NULL) { /*take action*/ }
// process some data
free(p);

if (!(q = malloc(sizeof(long long)*m))) { /*take action*/ }
for(i=0; i<m; ++i)
  p[i] = i - m;  // a typo!
//...
```

- Memory still there, but could have been reused!
- Or could have not been reused as well...
- Could appear to work, very difficult to catch
- Good advice: always zero a pointer after freeing it
  - Can be done “automagically” if you

    `#define free(ptr_var) (free(ptr_var), ptr_var = NULL)`

The Third Big Mistake with `free()`


```
typedef struct mydata {
  int n;
  double *somedata;
  int *moredata;
} mydata;

mydata *p = calloc(1, sizeof(mydata));
if (!p) { /* take action */ }

p->n = datasize;
p->somedata = calloc(datasize, sizeof(double));
p->moredata = calloc(datasize, sizeof(int));
if (!p->somedata || !p->moredata) { /* take action */ }

//input and process data

free(p);  // forgot something?
```

- Freeing `p`, `p->somedata` and `p->moredata` are gone, so we can't free their pointees, memory leak!
- Free `p->somedata` and `p->moredata` first, then `p`

Memory Friends from `string.h`

Function	Does
`void *memmove(void *d, const void *s, size_t len)`	copies a `len` bytes sized memory area from `s` to `d`, returns `d`
`void *memset(void *p, int val, size_t len)`	writes `len` copies of `(unsigned char)val` starting from address `p`, returns `p`

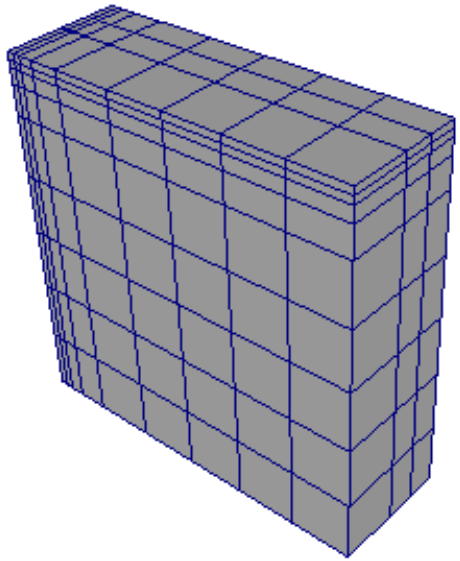
- You'll happen to encounter `memcpy()` too
  - Copies almost as `memmove()` does
  - If memory areas happen to overlap, `memmove()` is safe and does the right thing
  - While `memcpy()` could be faster, but is unsafe
  - Be prudent, and prefer `memmove()`
  - Surprisingly, `memmove()` is also faster in quite a few implementations!
- Way too common mistake: forgetting about and writing code doing the same
- Don't reinvent the wheel, use library functions!

Comfortable, and User Friendly


```
void my_pde_solver(int nx, int ny, int nz,
                   // physical parameters
                    ) {
//...
  double (*u)[ny][nz] = (double (*)[ny][nz])calloc(nx*ny*nz, sizeof(double));
  double (*v)[ny][nz] = (double (*)[ny][nz])calloc(nx*ny*nz, sizeof(double));
  double (*w)[ny][nz] = (double (*)[ny][nz])calloc(nx*ny*nz, sizeof(double));
  double (*p)[ny][nz] = (double (*)[ny][nz])calloc(nx*ny*nz, sizeof(double));

  if (u == NULL || v == NULL || w == NULL || p == NULL) {
    fprintf(stderr, "Not enough memory!\n");
    exit(exit_failure);
  }

  // solver code using u, v, w, and p in as humans do
```

- Now available memory is the limit
- And still easy to use

Nonuniform Grids



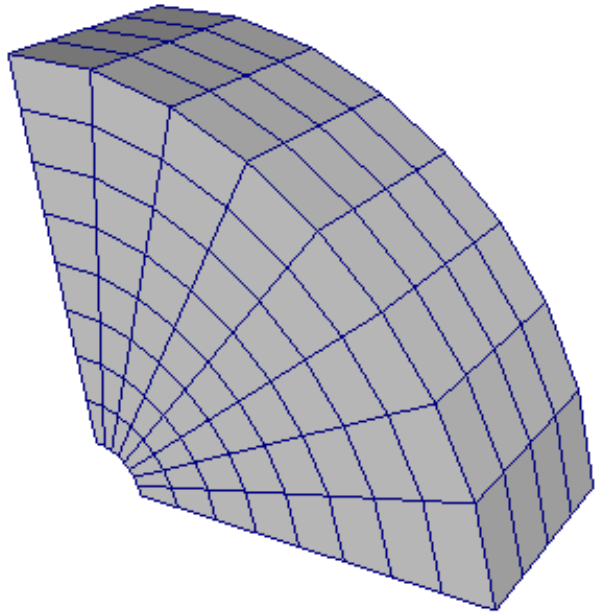
- Let's imagine we have to solve a PDE
- On a dense, Cartesian, non uniform grid
  - Mesh axes are parallel to coordinate ones
  - Steps along each direction differ in size from point to point

Keeping Information Together


```
typedef struct nonuniform_grid {
  int nx, ny, nz;

  double *deltax; // Grid steps
  double *deltay;
  double *deltaz;
} nonuniform_grid;
//...
nonuniform_grid my_grid;

//...

mygrid.deltax = calloc(nx - 1, sizeof(double));
mygrid.deltay = calloc(ny - 1, sizeof(double));
mygrid.deltaz = calloc(nz - 1, sizeof(double));
// Check immediately for NULL pointers!
```

- Related information is best kept together
- Grid size and grid steps are related information

Structured Grids in General Form



- Let's imagine we have to solve a PDE
- On a dense structured mesh
  - Could be continuously morphed to a Cartesian grid
  - Need to know coordinates of each mesh point

Sketching a Mesh Description


```
typedef vect3D meshpoint;
typedef vect3D normal;

typedef struct mesh {
  int nx, ny, nz;

  meshpoint *coords;

  normal *xnormals;
  normal *ynormals;
  normal *znormals;

  double *volumes;
} mesh;
//...
nonuniform_grid my_grid;

mygrid.coords = calloc(nx*ny*nz, sizeof(meshpoint));
mygrid.xnormals = calloc(nx*ny*nz, sizeof(normal));
mygrid.ynormals = calloc(nx*ny*nz, sizeof(normal));
mygrid.znormals = calloc(nx*ny*nz, sizeof(normal));
mygrid.volumes = calloc((nx-1)*(ny-1)*(nz-1), sizeof(double));
// Check immediately for NULL pointers!
```

- No VLAs allowed in structures
- Cast to VLA array pointer in functions using it

Multiblock Meshes and More

- A multiblock mesh is an assembly of connected structured meshes
  - You could dynamically allocate a **`mesh`** array
  - Or build a **`block`** type including a **`mesh`** and connectivity information
- Adaptive Mesh Refinement
  - You want your blocks resolution to adapt to dynamical behavior of PDE solution
  - Which means splitting blocks to substitute part of them with more resolved meshes
- Eventually, you'll need more advanced data structures
  - Like lists (and recursion comes handy)
  - Like binary trees, oct-trees, n-ary trees (and recursion becomes essential)

If You Read Code Like This...


```
struct block_item;

typedef struct block_item {
  block *this_block;

  struct block_item *next;
} block_item;

//...
   while (p) {
     advance_block_in_time(p->this_block);
     p = p->next;
   }
```

- It is processing a singly-linked list of mesh blocks
- You need to learn more on abstract data structures
- Don’t be afraid, it’s not that difficult

And If You Read Code Like This...


```
struct block_tree_node;

typedef struct block_tree_node {
  block *this_block;

  int children_no;
  struct block_tree_node **childrens;
} block_tree_node;

//...
void tree_advance_in_time(block_tree_node *p) {
   int i;

   for(i=0; i<p->children_no; ++i)
     tree_advance_in_time(p->childrens[i]);

   advance_block_in_time(p->this_block);
}
```

- It is processing a tree of mesh blocks (AMR, probably)
- You need to learn more on abstract data structures
- Don’t be afraid, it’s not that difficult

Outline

What We Left Out (1 of 2)

- More preprocessor magic, like:
  - lots of predefined macros to automatically adapt your code to platforms and compilers
  - macros to write function with variable number of arguments
- More types, like:
  - extended integer types
  - wide and Unicode characters and related facilities
  - unions and bit fields, mostly used for OS programming
- More facilities to:
  - control the floating point environment
  - interact with the process environment
  - localize your program
- More facilities for robustness:
  - static and dynamic assertions
  - bounds checking functions for I/O and string management (C11 Annex K)
  - precise control of process termination

What We Left Out (2 of 2)

- More facilities for performance:
  - `inline` functions
  - control of data alignment in memory
- C11 threads support
- More functions

- More C practice
  - That's your job

- More about programming
  - Code development management tools
  - Debugging tools
  - Look among Cineca HPC courses

Looking for More


ANSI WG14
C Standard and Technical Corrigenda
http://www.open-std.org/jtc1/sc22/wg14/www/standards
http://www.open-std.org/jtc1/sc22/wg14/www/docs/n1570.pdf


S. Summit
comp.lang.c Frequently Asked Questions
http://www.c-faq.com/


D. Dyer
The Top 10 Ways to get screwed by the "C" programming language
http://www.andromeda.com/people/ddyer/topten.html


S. Harbison, G. Steele
C A Reference Manual
Prentice Hall, 5th ed., 2002


A. Kelley, I. Pohl
C by Dissection: The Essentials of C Programming
Addison Wesley, 4th ed., 2000


A. Koenig
C Traps and Pitfalls
Addison Wesley, 1989

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