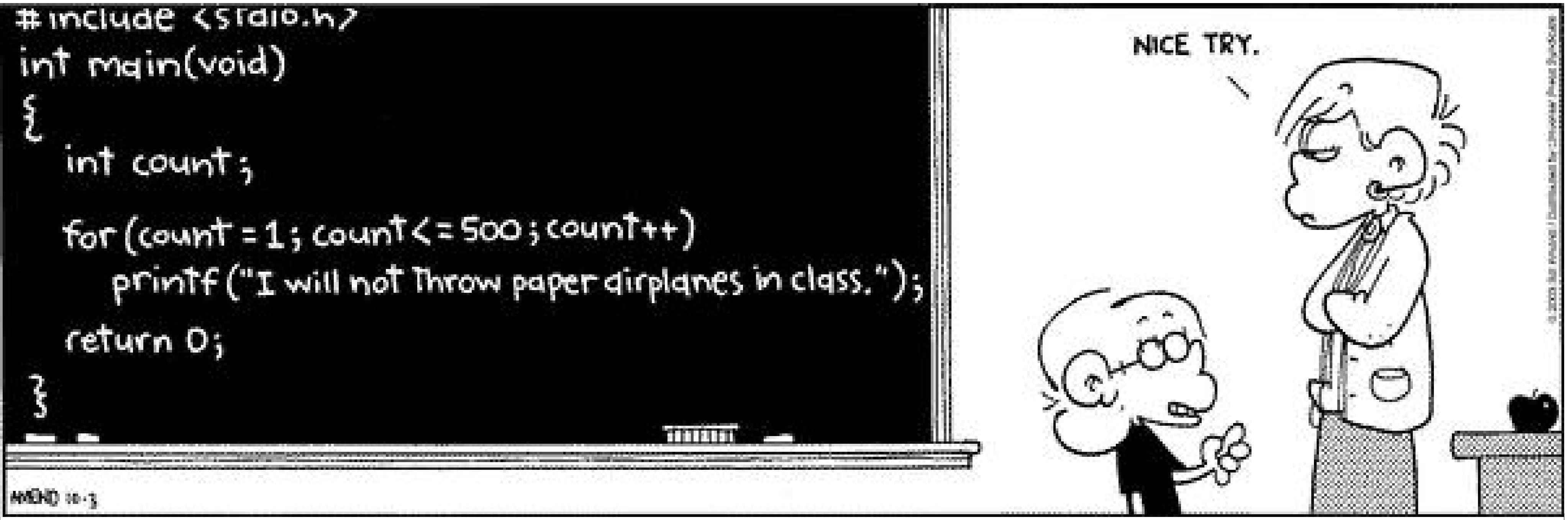
C – The Language



```
#include <stdio.h>
int main(void)
{
  int count;

  for(count = 1; count<=500; count++)
     printf("I will not Throw paper airplanes in class.");

  return 0;
}
```

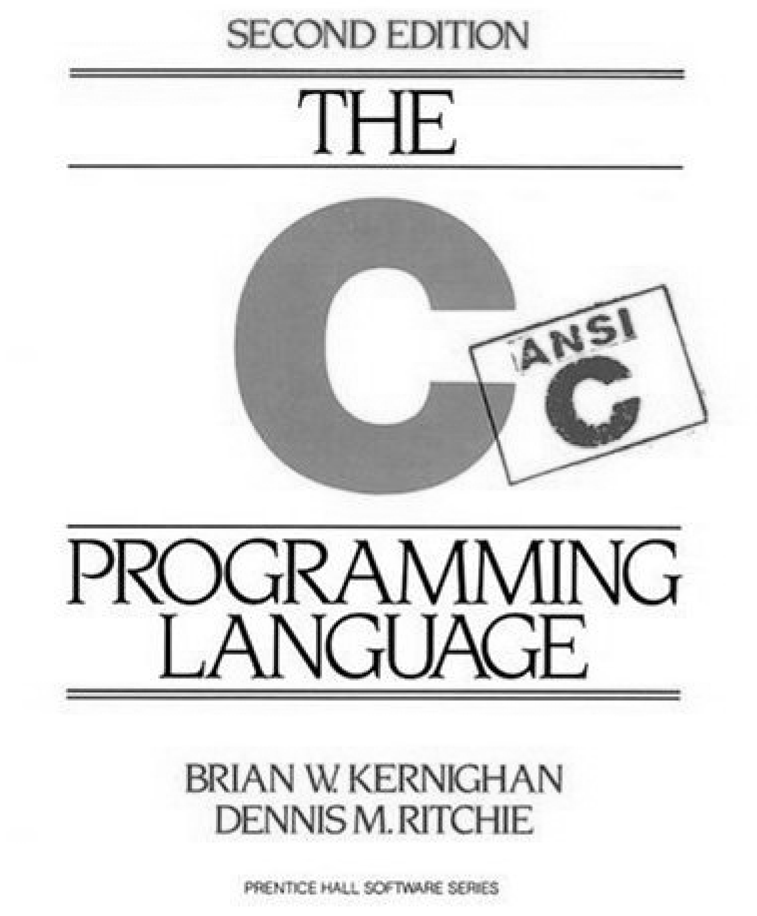
Topics

1) Background of C.
2) IDE for cross development.
3) Modular C programs and good design.
4) How to use printf(), strings, macros...

A Brief History Of C

K&R C

- Kernighan and Ritchie published book:
  "The C Programming Language" in 1978.
  - Developed at Bell Labs for Unix in 1969 by Ritchie.
    Note: Ritchie one of original UNIX authors.
  - Designed for writing system software.



Importance of K&R

Linux kernel style guide on where to put the {'s:

"...the preferred way, as shown to us by the prophets Kernighan and Ritchie, is to put the opening brace last on the line, and put the closing brace first, thusly:

```
if (x is true) {
    we do y
}
```

...However, there is one special case, namely functions: they have the opening brace at the beginning of the next line, thus:

```
int function(int x)
{
    body of function
}
```

Heretic people all over the world have claimed that this inconsistency is ... well ... inconsistent, but all right-thinking people know that (a) K&R are right and (b) K&R are right...."

Standards

- ANSI C (1989) / ISO C90
  - An updated version of K&R C.
  - First agreed on "standard".
- C99 update added these and more:
  - inline functions, mix variable declaration in function.
  - // commenting style
- C11 update added these and more:
  - threading support, Unicode support,
  - Bounds-checking string functions: strcat_s()
- A lot of code still written to ANSI C.
  - It works everywhere!

Important Things Missing vs C++

- No classes:
  - use structs for data,
    module-organization for code.
- No pass by reference: use pointers.
- No overloading (functions or operators)

Some Differences vs C++

- true and false defined in #include <stdbool.h>
  Use type bool
- const a little different vs C++
  (It’s not a compile-time constant, so cannot always declare other constants based on previous const)
  - C programs often use:
    #define MY_CONST 10
- C does not strictly enforce function arguments:

  ```
  void foo();    // could also be header for:
  void foo(char *msg, int size, double change) {...}
  ```

  -
  - Always include the correct headers & full prototypes.

IDE for Cross Development

Why an IDE?

- Integrated Development Environment (IDE)
  - IDEs have powerful editing features which support your efficiency.
    - Syntax highlighting, auto format, auto-complete
    - Integrated build and error display
    - Integrated graphical debugger.
- I recommend you setup an IDE for cross-development.
  - I will support VS Code and Eclipse.
  - Feel free to pick your favourite.

VS Code w/ Makefile

- Open VS Code in folder with makefile

  ```
  (host)$ code .
  ```

- Create makefile build task:
  Terminal --> Configure Task...
  - Select “Create tasks.json file from template”
  - Select “Others”
  - Set label to “build via makefile”
    Set command to “make”
- Set as default build task:
  Terminal --> Configure default build task...
  - Select “build via makefile”
- Build Project:
  Terminal --> Run Build Task (ctrl+shift+B)
  - Ctrl + Click filename in any build errors

CMake
Sample

Modular Design

Modular Design

- Cannot do OOD: no objects!
- Use a modular design where...
  - Each component's interface is its .h file.
  - Implementation is .c file
- When reviewing the *quality* of a large C program, I first look at how modular its components are.
  - If you do nothing else, learn this!

Naming Conventions

keypad.h

```
// “Public” functions/constants
#define KEYPAD_NUM_KEYS 10
bool Keypad_isSomeButtonDown();
```

keypad.c

```
// “Private” functions/variables
#define DEFAULT_BUTTON 0
static int buttonState = 0;
bool Keypad_isSomeButtonDown();
static void initButtons() {...}
```

-
  - Either inline (C99 //...) or block (/* ... */).
  - Comment static functions only when needed.
- Pick a consistent indentation style and stick with it.
  - Suggestion: Try the Linux Kernel style.

Linkage

- Function or global variable accessible in..

printer.c

```
int badGlobal = 1;
bool Printer_hasPaper() { ...}
```

other.c

```
extern badGlobal;
void foo() {
        badGlobal *= 2;
}
```

- Function or global variable accessible in..

printer.c

```
static int numPages = 0;
static void updatePaperStatus() { ... }
```

- Rule of thumb
  - Make functions and global variables static unless..

Fight “Globalization” (C Style)

- Getting rid of externally linked global variables
  - Turn a global variable into..
- Example
  - How could a printer module store the number of pages in the printer?
- Bad (in printer.c)

```
int Printer_pageCount = 0;
```

Other code can read and write this variable.

- Better (in printer.c)

```
static int pageCount = 0;
int Printer_getPageCount() {...}
void Printer_updatePageCount() {...}
```

All code to update the value found inside the module..

Card Deck Example

card.h

```
// Represent a single card.
#ifndef CARD_H_
#define CARD_H_

typedef struct {
	// Suit can be one of:
	//	'C', 'H', 'D', 'S'
	char suit;
	// Value can be one of:
	//	'2', ..., '9', 'J', 'Q', 'K', 'A'
	char value;
} sCard;

#endif
```

deck.h

```
// Manage a standard deck of cards.
#ifndef DECK_H_
#define DECK_H_

#include "card.h"

#define NUM_CARDS_IN_DECK 52

void	Deck_initialize(void);
sCard	Deck_getNextCard(void);
int	Deck_getNumCards(void);

#endif
```

Card Deck Example (cont)

deck.c

```
#include "deck.h"
#include <stdbool.h>

static sCard cards[NUM_CARDS_IN_DECK];
static bool initialized = false;
static int numCardsLeft = 0;

// Local Headers (for inside .c file only)
static void populateCards(void);
static void shuffleCards(void);
static void removeTopCard(void);
```

..

Need headers so these functions can be called regardless of order in file.

Card Deck Example (cont)

```
// deck.c continued...
void Deck_initialize(void)
{
    populateCards();
    shuffleCards();
    initialized = true;
}
static void populateCards(void)
{
    for (int i = 0; i < NUM_CARDS_IN_DECK; i++) {
        /*...*/
    }
}
static void shuffleCards(void)
{   /*...*/  }


...
```

Call functions with internal linkage; implementations is below here, so must have the headers.

Variable in for loop requires C99

Example

- Modular design of SFU's electronic lab-door locks.
  - What modules?
  - What functions in each module?

Real C: Example 1

AGC_Processing.h

(AGC is Automatic Gain Control, to make audio volume seem consistent)

```
void Proc_AGC(void);
void Init_AGC (void);

// Global variables exposed by AGC module
extern int   PGAGain;
extern int   AGC_Mode;
extern float DDeltaPGA;



extern float   AGC_Mag;
extern int              RSL_Mag;

extern int PGAGAIN0;
extern int dac_gain;
extern int      AGC_Signal;

extern int AGC_On;
extern int Old_PGAGAIN0;
extern int Old_dac_gain;

extern int RSL_Cal;
```

Real C: Example 2

options.h

```
// This sequence must be the same as options.c
typedef enum {
	OPTION_RX_AUDIO = 0,
	OPTION_RX_RF,
	OPTION_AGC_Mode,
	NUM_OPTIONS
} OptionNumber;

// Initialization
void Options_Initialize(void);
void Options_ResetToDefaults(void);

// Work with option data
const char* Options_GetName(int optionIdx);
int16_t Options_GetValue(int optionIdx);
void     Options_SetValue(int optionIdx, int16_t newValue);
uint16_t Options_GetMinimum(int optionIdx);
uint16_t Options_GetMaximum(int optionIdx);
uint16_t Options_GetChangeRate(int optionIdx);
```

Some C Details

C Dynamic Allocation

- No "new"; use malloc():

```
#include <stdlib.h>
#define NUM_TREES 5

void foo() {
        // What's going on here?
        float *pHeights;
        pHeights = malloc(sizeof(*pHeights) * NUM_TREES);

        if (!pHeights)
                exit (EXIT_FAILURE);
        ....
```

malloc() arg is #bytes to allocate

- Free memory using free():

```
        free(pHeights);
        pHeights = NULL;
```

For safety.
2nd free does nothing.
(no dangling pointer)

printf

C Code:

```
printf("char       %c\n",  'c');
printf("decimal    %d\n",  100);
printf("string     %s\n",  "Hello");
printf("float      %f\n",  3.14);
printf("hex        %x\n",  0xDEADC0DE);
printf("unsigned   %u\n",  4000000000U);
printf("size_t     %zu\n", strlen(“hi”);


printf("Cash $%05.2f\n", 0.1);
```

Output:

```
char      c
decimal   100
string    Hello
float     3.140000
hex       deadc0de
unsigned  4000000000
size_t    2


Cash      $00.10
```

#define, #ifdef

```
// Use #define for constants:
#define NUM_SHEEP 100      //...
#define PROMPT "Hello> "
#define DEBUG_LEVEL 2

// Selective Compilation:
#ifdef DEBUG_BUTTONS
    printf("Button read: \n", daButton);
#endif

#if DEBUG_LEVEL > 3
    printf("Button read: \n", daButton);
#endif
```

Strings

- C Strings
  - ..
- Example

```
char buff[100];
snprintf(buff, 100, “Hi”);
```

- Forgetting null is a **common** bug!
  - Use string functions with ‘n’ in name: they are passed the size of the buffer
  - Avoids buffer overflow

Tim Mossholder [Pexels]

Strings: snprintf, strnlen, strncmp

```
#define BIG 100
#define DAYS_PER_YEAR 365
void demoBasics()
{
    char buff[BIG];
    int numYears = 4;


    sprintf(buff, "that is %d days",
          numYears * DAYS_PER_YEAR);

    printf("%s\n", buff);

    printf("%zu\n", strnlen(buff, BIG));

    printf("%d\n", strncmp(buff, "that", BIG));
}
```

```
that is 1460 days
```

```
17
```

```
-1
```

- Spot the bug
  - What if: #define BIG 13?

Strings: Copy

```c
#define BIG 100

void demoCopyToBuff()
{
   const int SMALL = 5;
   char buff[BIG];
   char smallBuff[SMALL];

   snprintf(buff, BIG, "Hello world (%d)!", 433);

   strncpy(smallBuff, buff, SMALL);
   smallBuff[SMALL-1] = 0;


   printf("Source:  %s\n", buff);
   printf("Target:  %s\n", smallBuff);
}
```

$ man strncpy
... Warning: If there is no null byte among the first n bytes of src, the string placed in dest will not be null-terminated.

```
Source:  Hello world (433)!
```

```
Target:  Hell
```

Strings: Append

```c
#define BIG 100
void demoAppend()
{
    char buff[BIG];
    snprintf(buff, BIG, "Hello CMPT %d", 433);

    // More safely append to end.
    int freeSpace = BIG - strnlen(buff,BIG) - 1;
    strncat(buff, " world!", freeSpace);



    printf("%s\n", buff);
}
```

$ man strncat
... As with strcat(), the resulting string in dest is always null-terminated.

```
Hello CMPT 433 world!
```

Strings: Append

```
void demoAppendAbuse()
{
    const size_t maxLen = 16;
    char buff[maxLen];
    snprintf(buff, maxLen, "Your grade is ");

    // Append (without overflow)
    const char* copyMe = "AN F!";
    size_t freeSpace = maxLen - strnlen(buff, maxLen) - 1;

    // Checking for truncation
    if (strlen(copyMe) > freeSpace) {
        err(EXIT_FAILURE, "Err: String would be truncated");
    }
    strncat(buff, copyMe, freeSpace);
    printf("%s\n", buff);
}
```

Err: String would be truncated

Your grade is A

Functions to Avoid (“banned”)

- String functions without size (“n”):
  - strcat()
  - strtok(), strtok_r()
  - sprintf(), vsprintf()
  - gets()
- May not null-terminate strings
  - strcpy(), strncpy()
- Problematic
  - strncat()

    Must calculate how many characters can be added

    Will truncate what’s being copied without warning (truncated string could be problematic!)

Strings: Number from String

```
void demoToInt()
{
    long fromStr = atol("-987654321");
    printf("%ld\n", fromStr);

    #define BASE 16
    long fromHexStr = strtol("0xDEADCODE", NULL, BASE);
    printf("%ld\n", fromHexStr);
}
```

```
-987654321
```

```
912092
```

Macros

Put brackets around parameters:

```
#define WTOD(w) ( (w) * 7)
#define BAD_WTOD(w) ( w * 7)
...
int days = BAD_WTOD (1+2);
```

Multi-line and statements:

```
#define WAIT_LONG() do {\
            sleep();\
            sleep();\
            sleep();\
      } while(0)
```

```
#define MIN(x, y) ( (x) < (y)? (x) : (y))
```

```
// Avoid side effects:
int a = 1, b = 10;
int c = MIN(a++, b++);
// becomes:
```

```
// Error during compilation.
#error "Die here!"
```

Loop variable and Struct

- Only in C99 can declare variables in for loop initializer:
  - C99:
    ```
    for (int i=0; i<10; i++) {
        ...
    }
    ```
  - ANSI (old-school):
    ```
    int i;
    for (i=0; i<10; i++){
        ...
    }
    ```
- Struct
  ```
  #define MAX_LEN 200
  struct student_t {
      char  name[MAX_LEN];
      int   age;
      float height;
  };

  struct student_t s1;
  ```
-

Example

- Class Exercise
  Design interface for joystick module
  - initialize, cleanup,
  - check if joystick pressed in a specific direction
  - get the name (string) for a joystick direction.
- Show Implementation
  Use an array of structs inside the module to store information about the directions.

Error Handling

Return Values

- C Functions often..

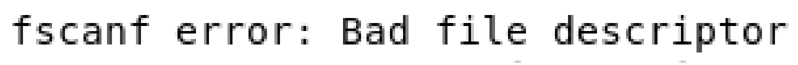
- Returning Success / Fail
  - Some functions return 0 or 1 to indicate success; -1, or 0 to indicate failure
  - Ex: fclose(): 0 for success, EOF (-1) for failure.

```
if (fclose(my_file) == EOF) {
    perror(“Unable to close file.”);
    exit(EXIT_FAILURE);
}
```

errno

- errno: Error code
  - ..
    to track which error was encountered
  - C library functions and system calls can set errno to indicate which error occurred (if any)
- exit(): terminates program
  - exit(EXIT_SUCCESS);
  - exit(EXIT_FAILURE);
- perror() prints a message based on errno:

```
char ch;
if (fscanf(myFile, "%c", &ch) == EOF) {
    perror("fscanf error");
    exit(EXIT_FAILURE);
}
```



```
fscanf error: Bad file descriptor
```

In-Band Error Indicators

- In-band Error Indicators
  - Many functions return useful information
    Ex: int ch = getchar();
  - These functions may indicate an error by returning a value not otherwise possible.
- getchar()’s Error Reporting
  - Returns a character (0 to 255?) on success,
    or EOF (-1, likely) on failure
  - Common usage:

```
int ch;
while ( (ch = getchar()) != EOF) {
   do_something(ch);
}
```

Some C Standard Library Functions

C Library Function	**Return Value on Success**	**Return Value on Failure**
`fclose()`	`0`	`EOF` (negative)
`fgetc()`	Character read	`EOF`
`fgets()`	Pointer to string	`NULL`
`fopen()`	Pointer to stream	`NULL`
`scanf()`	Number of conversions (nonnegative)	`EOF` (negative)
`sprintf()`	Number of non-null characters written	Negative
`strtol()`	Converted value	`LONG_MAX` or `LONG_MIN`, `errno == ERANGE`
`time()`	Calendar time	`(time_t)(-1)`

Summary

- Version of C: K&R, Ansi C/C90, C99, C11
- Use a powerful IDE for cross development.
- Use modular design & naming convention.
- Details:
  - malloc() & free()
  - printf() types: %c, %d, %s, %f, %x, %u
  - #define, #ifdef
  - String functions: sprintf(), strncmp(), strncpy(), strlen()...
  - Macros: Put parameters in brackets.
- Carefully check for errors; use errno, perror()