Brief Introduction to the C Programming Language

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Introduction

- The C programming language was designed by Dennis Ritchie at Bell Laboratories in the early 1970s
- Influenced by
  - ALGOL 60 (1960),
  - CPL (Cambridge, 1963),
  - BCPL (Martin Richard, 1967),
  - B (Ken Thompson, 1970)
- Traditionally used for systems programming, though this may be changing in favor of C++
- Traditional C:
  - *The C Programming Language*, by Brian Kernighan and Dennis Ritchie, 2nd Edition, Prentice Hall
  - Referred to as *K&R*

Standard C

- Standardized in 1989 by ANSI (American National Standards Institute) known as ANSI C
- International standard (ISO) in 1990 which was adopted by ANSI and is known as *C89*
- As part of the normal evolution process the standard was updated in 1995 (*C95*) and 1999 (*C99*)
- C++ and C
  - C++ extends C to include support for Object Oriented Programming and other features that facilitate large software development projects
  - C is not strictly a subset of C++, but it is possible to write "*Clean C*" that conforms to both the C++ and C standards.

Elements of a C Program

- A C development environment includes
  - *System libraries* and *headers*: a set of standard libraries and their header files. For example see `/usr/include` and `glibc`.
  - *Application Source*: application source and header files
  - *Compiler*: converts source to object code for a specific platform
  - *Linker*: resolves external references and produces the executable module
- User program structure
  - there must be one main function where execution begins when the program is run. This function is called main
    - `int main (void) { ... },`
    - `int main (int argc, char *argv[]) { ... }`
    - UNIX Systems have a 3rd way to define main(), though it is not POSIX.1 compliant
      `int main (int argc, char *argv[], char *envp[])`
  - additional local and external functions and variables

A Simple C Program

- *Create* example file: `try.c`
- *Compile* using gcc:
  `gcc –o try try.c`
- The standard C library *libc* is included automatically
- *Execute* program
  `./try`
- Note, I always specify an absolute path
- Normal termination:
  `void exit(int status);`
  - calls functions registered with `atexit()`
  - flush output streams
  - close all open streams
  - return status value and control to host environment

```
/* you generally want to
 * include stdio.h and
 * stdlib.h
 * */
#include <stdio.h>
#include <stdlib.h>

int main (void)
{
   printf("Hello World\n");
   exit(0);
}
```

Source and Header files

- Just as in C++, place related code within the same module (i.e. file).
- Header files (`*.h`) export interface definitions
  - function prototypes, data types, macros, inline functions and other common declarations
- Do not place source code (i.e. definitions) in the header file with a few exceptions.
  - inline'd code
  - class definitions
  - const definitions
- *C preprocessor* (`cpp`) is used to insert common definitions into source files
- There are other cool things you can do with the preprocessor

Another Example C Program

/usr/include/stdio.h

```
/* comments */
#ifndef _STDIO_H
#define _STDIO_H

... definitions and protoypes

#endif
```

/usr/include/stdlib.h

```
/* prevents including file
 * contents multiple
 * times */
#ifndef _STDLIB_H
#define _STDLIB_H

... definitions and protoypes

#endif
```

`#include` directs the preprocessor to "include" the contents of the file at this point in the source file. `#define` directs preprocessor to define macros.

example.c

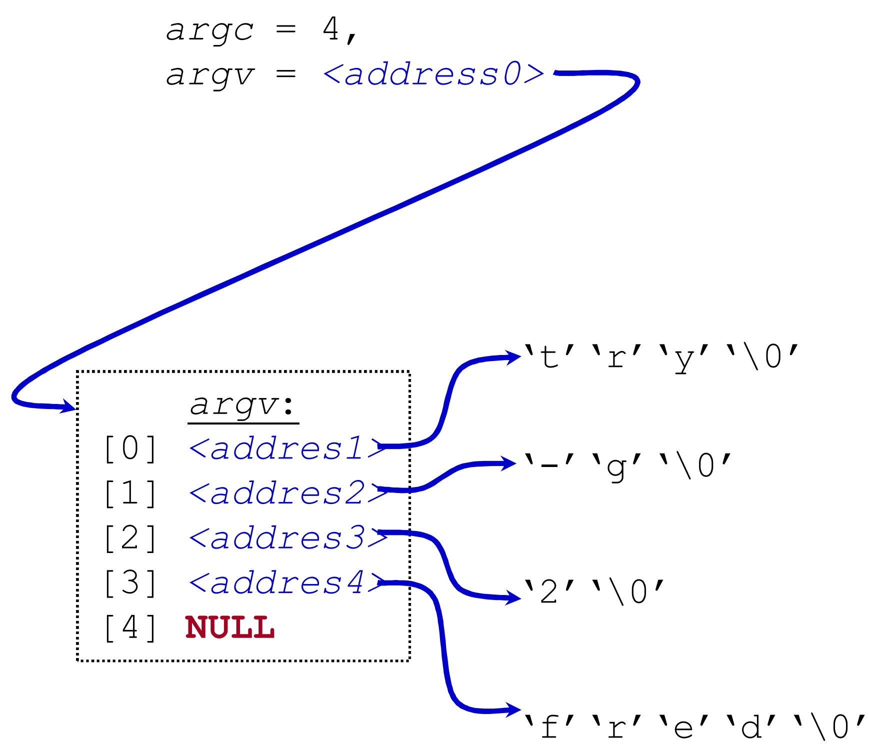
```
/* this is a C-style comment
 * You generally want to palce
 * all file includes at start of file
 * */
#include <stdio.h>
#include <stdlib.h>

int
main (int argc, char **argv)
{
   // this is a C++-style comment
   // printf prototype in stdio.h
  printf("Hello, Prog name = %s\n",
               argv[0]);
  exit(0);
}
```

Passing Command Line Arguments

- When you execute a program you can include arguments on the command line.
- The run time environment will create an argument vector.
  - `argv` is the argument vector
  - `argc` is the number of arguments
- Argument vector is an array of pointers to strings.
- a *string* is an array of characters terminated by a binary 0 (NULL or '\0').
- *argv[0]* is always the program name, so *argc* is at least 1.

```
./try -g 2 fred
```



C Standard Header Files you may want to use

- Standard Headers you should know about:
  - `stdio.h` - file and console (also a file) IO: *perror, printf, open, close, read, write, scanf,* etc.
  - `stdlib.h` - common utility functions: *malloc, calloc, strtol, atoi,* etc
  - `string.h` - string and byte manipulation: *strlen, strcpy, strcat, memcpy, memset,* etc.
  - `ctype.h` - character types: *isalnum, isprint, isupport, tolower,* etc.
  - `errno.h` - defines *errno* used for reporting system errors
  - `math.h` - math functions: *ceil, exp, floor, sqrt,* etc.
  - `signal.h` - signal handling facility: *raise, signal,* etc
  - `stdint.h` - standard integer: *intN_t, uintN_t,* etc
  - `time.h` - time related facility: *asctime, clock, time_t,* etc.

The Preprocessor

- The C preprocessor permits you to define simple macros that are evaluated and expanded prior to compilation.

- Commands begin with a '#'. Abbreviated list:
  - `#define` : defines a macro
  - `#undef` : removes a macro definition
  - `#include` : insert text from file
  - `#if` : conditional based on value of expression
  - `#ifdef` : conditional based on whether macro defined
  - `#ifndef` : conditional based on whether macro is not defined
  - `#else` : alternative
  - `#elif` : conditional alternative
  - `defined()` : preprocessor function: 1 if name defined, else 0

```
#if defined(__NetBSD__)
```

Preprocessor: Macros

- Using macros as functions, exercise caution:
  - flawed example: `#define mymult(a,b) a*b`
    - Source: `k = mymult(i-1, j+5);`
    - Post preprocessing: `k = i – 1 * j + 5;`
  - better: `#define mymult(a,b) (a)*(b)`
    - Source: `k = mymult(i-1, j+5);`
    - Post preprocessing: `k = (i – 1)*(j + 5);`
- Be careful of *side effects*, for example what if we did the following
  - Macro: `#define mysq(a) (a)*(a)`
  - flawed usage:
    - Source: `k = mysq(i++)`
    - Post preprocessing: `k = (i++)*(i++)`
- Alternative is to use inline'ed functions
  - `inline int mysq(int a) {return a*a};`
  - `mysq(i++)` works as expected in this case.

Preprocessor: Conditional Compilation

- Its generally better to use inline'ed functions
- Typically you will use the preprocessor to define constants, perform conditional code inclusion, include header files or to create shortcuts
- `#define DEFAULT_SAMPLES  100`
- `#ifdef __linux`

```
static inline int64_t
  gettime(void) {...}
```

- `#elif defined(sun)`

```
static inline int64_t
  gettime(void) {return (int64_t)gethrtime()}
```

- `#else`

```
static inline int64_t
  gettime(void) {... gettimeofday()...}
```

- `#endif`

Another Simple C Program

```
int main (int argc, char **argv) {
  int i;
  printf("There are %d arguments\n", argc);
  for (i = 0; i < argc; i++)
    printf("Arg %d = %s\n", i, argv[i]);

  return 0;
}
```

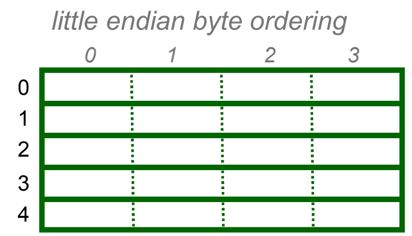
- Notice that the syntax is similar to Java
- What's new in the above simple program?
  - of course you will have to learn the new interfaces and utility functions defined by the C standard and UNIX
  - Pointers will give you the most trouble

Arrays and Pointers

- A variable declared as an array represents a contiguous region of memory in which the array elements are stored.

  `int x[5]; // an array of 5 4-byte ints.`

- All arrays begin with an index of 0



memory layout for array x

- An array identifier is equivalent to a pointer that references the first element of the array
  - `int x[5], *ptr;`

    `ptr = &x[0]` is equivalent to `ptr = x;`

- Pointer arithmetic and arrays:
  - `int x[5];`

    `x[2]` is the same as `*(x + 2)`, the compiler will assume you mean 2 objects beyond element x.

Pointers

- For any type T, you may form a pointer type to T.
  - Pointers may reference a function or an object.
  - The value of a pointer is the address of the corresponding object or function
  - Examples: `int *i; char *x; int (*myfunc)();`
- Pointer operators: * dereferences a pointer, & creates a pointer (reference to)
  - ```
    int i = 3; int *j = &i;
    *j = 4; printf("i = %d\n", i); // prints i = 4
    ```
  - ```
    int myfunc (int arg);
    int (*fptr)(int) = myfunc;
    i = fptr(4); // same as calling myfunc(4);
    ```
- Generic pointers:
  - Traditional C used (char *)
  - Standard C uses (void *) – these can not be dereferenced or used in pointer arithmetic. So they help to reduce programming errors
- Null pointers: use ***NULL*** or ***0***. *It is a good idea to always initialize pointers to NULL.*

Pointers in C (and C++)

Step 1:

```
int main (int argc, argv) {
 int  x = 4;
 int *y = &x;
 int *z[4] = {NULL, NULL, NULL, NULL};
 int  a[4] = {1, 2, 3, 4};
...
```

	Program Memory	Address
x	**4**	0x3dc
y	**0x3dc**	0x3d8
	NA	0x3d4
	NA	0x3d0
z[3]	**0**	0x3cc
z[2]	**0**	0x3c8
z[1]	**0**	0x3c4
z[0]	**0**	0x3c0
a[3]	**4**	0x3bc
a[2]	**3**	0x3b8
a[1]	**2**	0x3b4
a[0]	**1**	0x3b0

Note: The compiler converts z[1] or *(z+1) to

Value at address (*Address of z + sizeof(int)*);

In C you would write the byte address as:

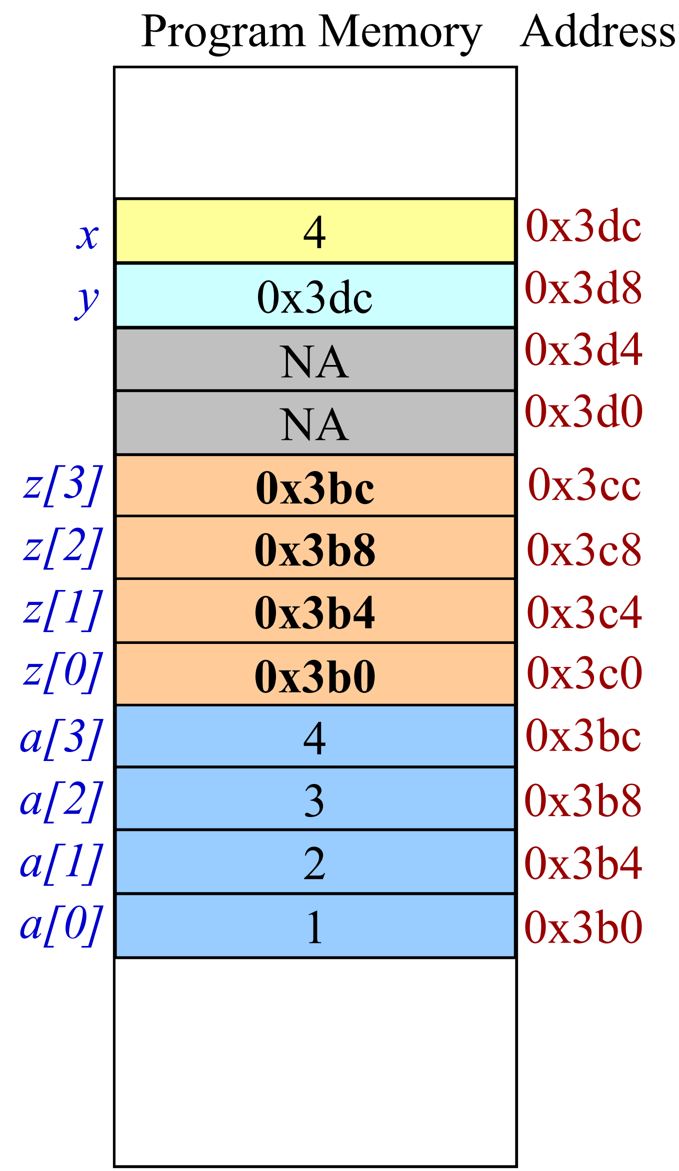
```
(char *)z + sizeof(int);
```

or letting the compiler do the work for you

```
(int *)z + 1;
```

Pointers Continued

```
Step 1:
int main (int argc, argv) {
  int  x = 4;
  int *y = &x;
  int *z[4] = {NULL, NULL, NULL, NULL};
  int  a[4] = {1, 2, 3, 4};
Step 2: Assign addresses to array Z
  z[0] = a;      // same as &a[0];
  z[1] = a + 1; // same as &a[1];
  z[2] = a + 2; // same as &a[2];
  z[3] = a + 3; // same as &a[3];
```



Pointers Continued

```
Step 1:
int main (int argc, argv) {
  int x = 4;
  int *y = &x;
  int *z[4] = {NULL, NULL, NULL, NULL};
  int a[4] = {1, 2, 3, 4};
Step 2:
  z[0] = a;
  z[1] = a + 1;
  z[2] = a + 2;
  z[3] = a + 3;
Step 3: No change in z's values
  z[0] = (int *)((char *)a);
  z[1] = (int *)((char *)a
                  + sizeof(int));
  z[2] = (int *)((char *)a
                  + 2 * sizeof(int));
  z[3] = (int *)((char *)a
                  + 3 * sizeof(int));
```

	Program Memory	Address
x	4	0x3dc
y	0x3dc	0x3d8
	NA	0x3d4
	NA	0x3d0
z[3]	**0x3bc**	0x3cc
z[2]	**0x3b8**	0x3c8
z[1]	**0x3b4**	0x3c4
z[0]	**0x3b0**	0x3c0
a[3]	4	0x3bc
a[2]	3	0x3b8
a[1]	2	0x3b4
a[0]	1	0x3b0

Getting Fancy with Macros

```
#define QNODE(type)   \
struct {              \
  struct type *next;  \
  struct type **prev; \
}

#define QNODE_INIT(node, field)   \
  do {                            \
    (node)->field.next = (node);  \
    (node)->field.prev =          \
            &(node)->field.next;  \
  } while ( /* */ 0 );

#define QFIRST(head, field) \
        ((head)->field.next)

#define QNEXT(node, field) \
        ((node)->field.next)

#define QEMPTY(head, field) \
        ((head)->field.next == (head))

#define QFOREACH(head, var, field) \
  for ((var) = (head)->field.next; \
       (var) != (head);            \
       (var) = (var)->field.next)
```

```
#define QINSERT_BEFORE(loc, node, field) \
  do {                                  \
    *(loc)->field.prev = (node);        \
    (node)->field.prev =                \
           (loc)->field.prev;           \
    (loc)->field.prev  =                \
           &((node)->field.next);       \
    (node)->field.next = (loc);         \
  } while (/* */0)

#define QINSERT_AFTER(loc, node, field)           \
  do {                                           \
    ((loc)->field.next)->field.prev =            \
            &(node)->field.next;                 \
    (node)->field.next = (loc)->field.next;      \
    (loc)->field.next = (node);                  \
    (node)->field.prev = &(loc)->field.next;     \
  } while ( /* */ 0)

#define QREMOVE(node, field)                          \
  do {                                                \
    *((node)->field.prev) = (node)->field.next;       \
    ((node)->field.next)->field.prev =                \
            (node)->field.prev;                       \
    (node)->field.next = (node);                      \
    (node)->field.prev = &((node)->field.next);       \
  } while ( /* */ 0)
```

After Preprocessing and Compiling

```
typedef struct wth_t
{
  int state;
  QNODE(wth_t) alist;
} wth_t;
```

CPP

```
typedef struct wth_t {
  int state;
  struct {
    struct wth_t *next;
    struct wth_t **prev;
  } alist;
```

```
#define QNODE_INIT(node, field)               \
  do {                                        \
    (node)->field.next = (node);              \
    (node)->field.prev = &(node)->field.next;\
  } while ( /* */ 0 );
```

after GCC

} ***head***: instance of wth_t

0x100	0
0x104	0x00100
0x108	0x00104

QNODE_INIT(head, alist)

3 words in memory

<*integer*> state
<*address*> next
<*address*> prev

QNODE Manipulations

before

	head
0x100	0
0x104	0x100
0x108	0x104

	node0
0x1a0	0
0x1a4	0x1a0
0x1a8	0x1a4

```
#define QINSERT_BEFORE(head, node, alist)\
  do {                                          \
     *(head)->alist.prev = (node);              \
     (node)->alist.prev = (head)->alist.prev;   \
     (head)->alist.prev  = &(node)->alist.next;\
     (node)->alist.next = (head);               \
  } while (/* */0)
```

QINSERT_BEFORE(head, node0, alist);

?

QNODE Manipulations

before

head

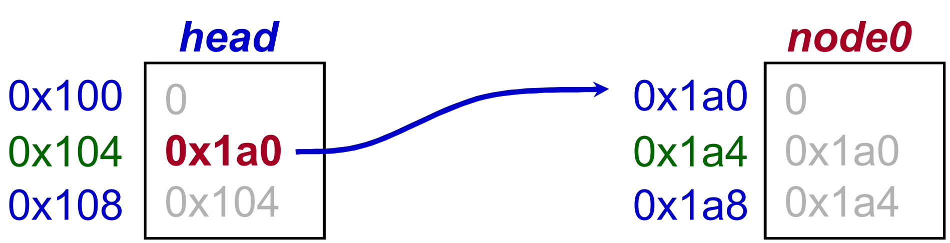
0x100	0
0x104	0x100
0x108	0x104

node0

0x1a0	0
0x1a4	0x1a0
0x1a8	0x1a4

```
#define QINSERT_BEFORE(head, node, alist)\
  do {                                      \
    *(head)->alist.prev = (node);           \
    (node)->alist.prev = (head)->alist.prev;  \
    (head)->alist.prev  = &(node)->alist.next;\
    (node)->alist.next = (head);            \
  } while (/* */0)
```

QINSERT_BEFORE(head, node0, alist);



QNODE Manipulations

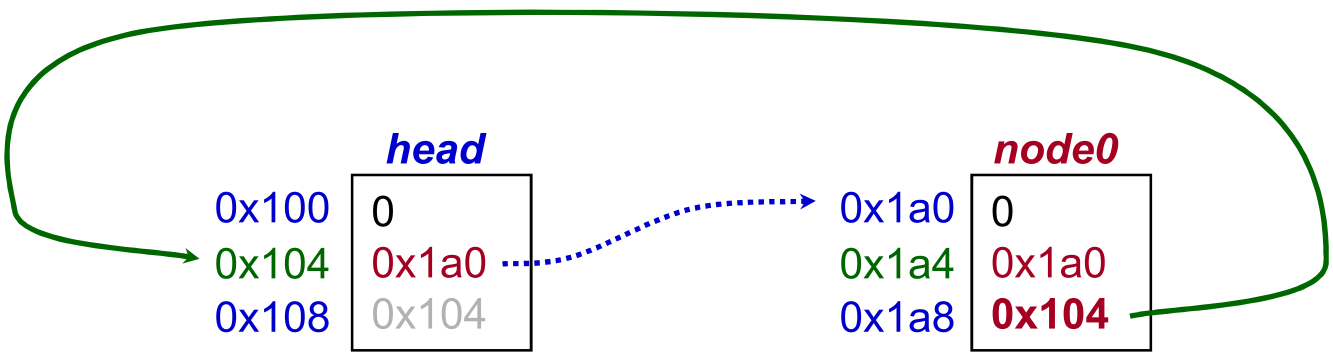
before

	head
0x100	0
0x104	0x100
0x108	0x104

	node0
0x1a0	0
0x1a4	0x1a0
0x1a8	0x1a4

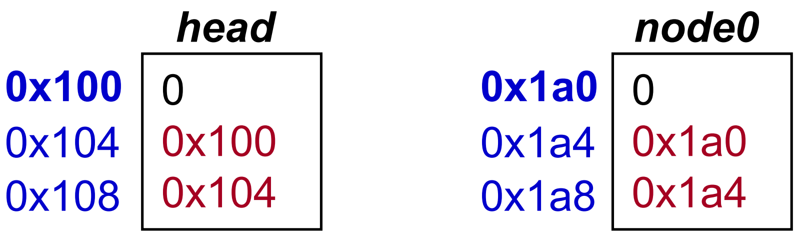
```
#define QINSERT_BEFORE(head, node, alist)\
  do {                                               \
     *(head)->alist.prev = (node);                  \
     (node)->alist.prev = (head)->alist.prev;       \
     (head)->alist.prev  = &(node)->alist.next;\
     (node)->alist.next = (head);                   \
  } while (/* */0)
```

QINSERT_BEFORE(head, node0, alist);



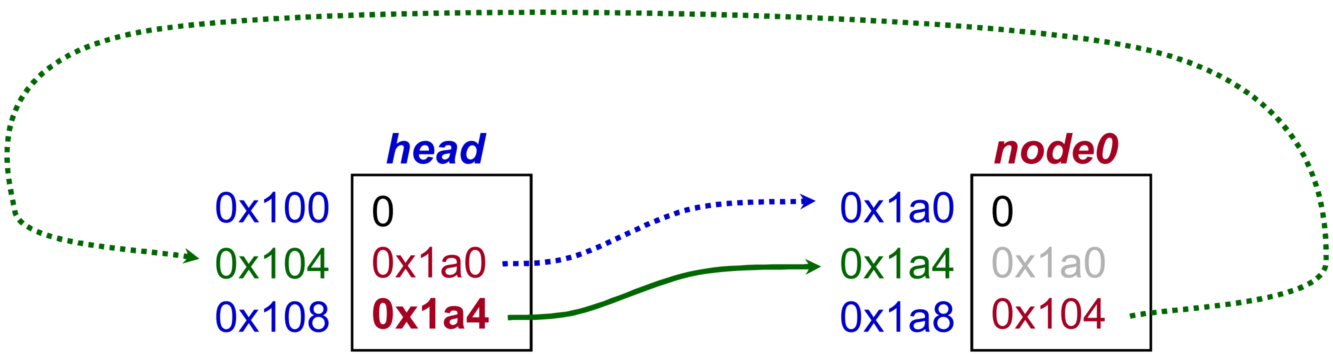
QNODE Manipulations

before




```
#define QINSERT_BEFORE(head, node, alist)\
  do {                                          \
    *(head)->alist.prev = (node);               \
    (node)->alist.prev = (head)->alist.prev;    \
    (head)->alist.prev  = &(node)->alist.next;\
    (node)->alist.next = (head);                \
  } while (/* */0)
```

QINSERT_BEFORE(head, node0, alist);



QNODE Manipulations

before

head

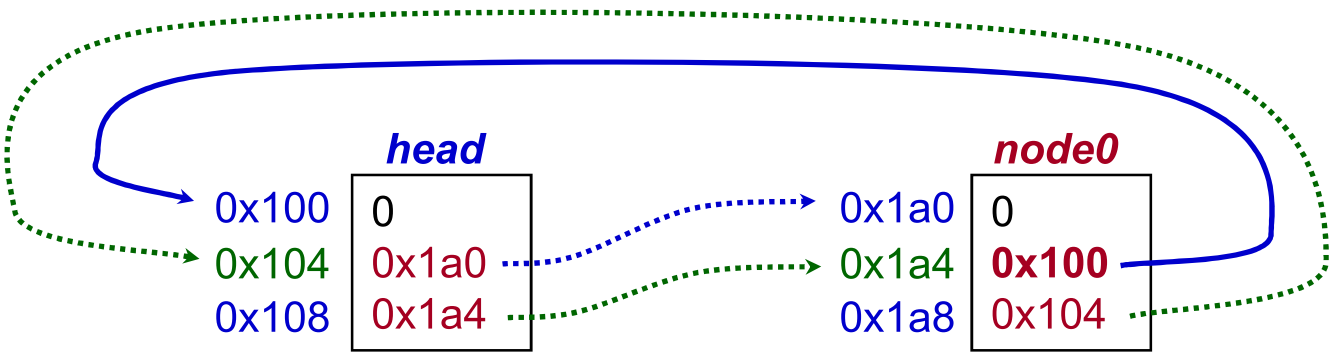
0x100	0
0x104	0x100
0x108	0x104

node0

0x1a0	0
0x1a4	0x1a0
0x1a8	0x1a4

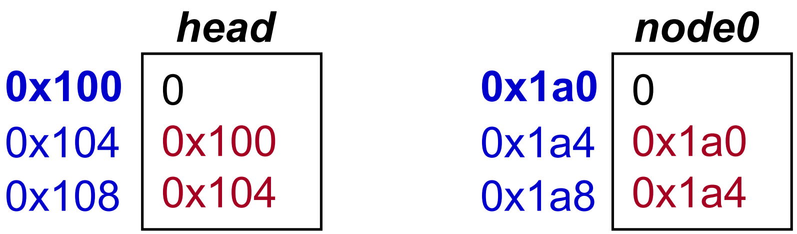
```
#define QINSERT_BEFORE(head, node, alist)\
  do {                                              \
    *(head)->alist.prev = (node);                   \
    (node)->alist.prev = (head)->alist.prev;        \
    (head)->alist.prev  = &(node)->alist.next;\
    (node)->alist.next = (head);                    \
  } while (/* */0)
```

QINSERT_BEFORE(head, node0, alist);



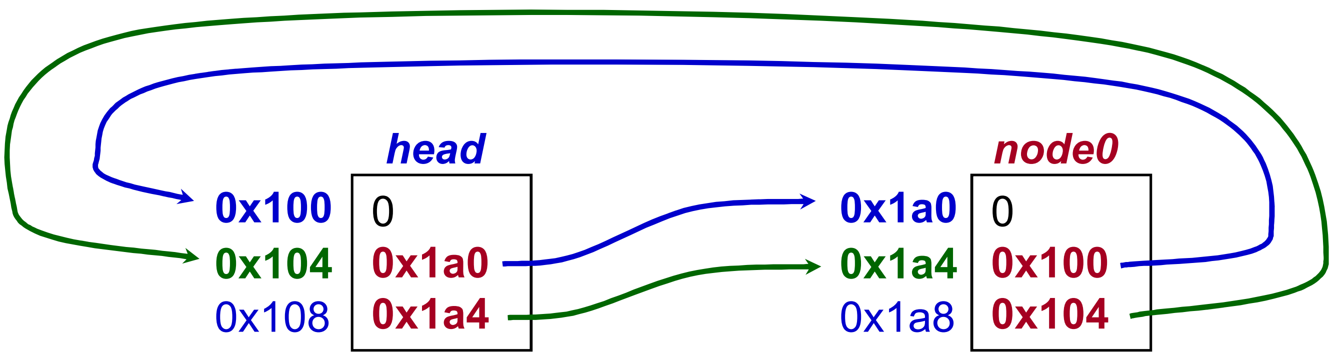
QNODE Manipulations

before




```
#define QINSERT_BEFORE(head, node, alist)\
  do {                                         \
    *(head)->alist.prev = (node);              \
    (node)->alist.prev = (head)->alist.prev;   \
    (head)->alist.prev  = &(node)->alist.next;\
    (node)->alist.next = (head);               \
  } while (/* */0)
```

QINSERT_BEFORE(head, node0, alist);



Adding a Third Node

head

0x100	0
0x104	0x1a0
0x108	0x1a4

node0

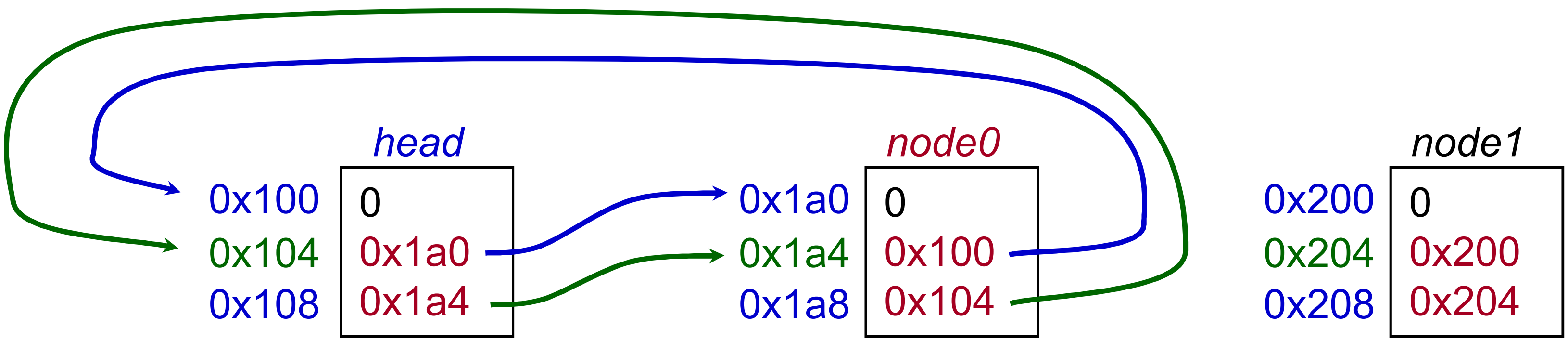
0x1a0	0
0x1a4	0x100
0x1a8	0x104

node1

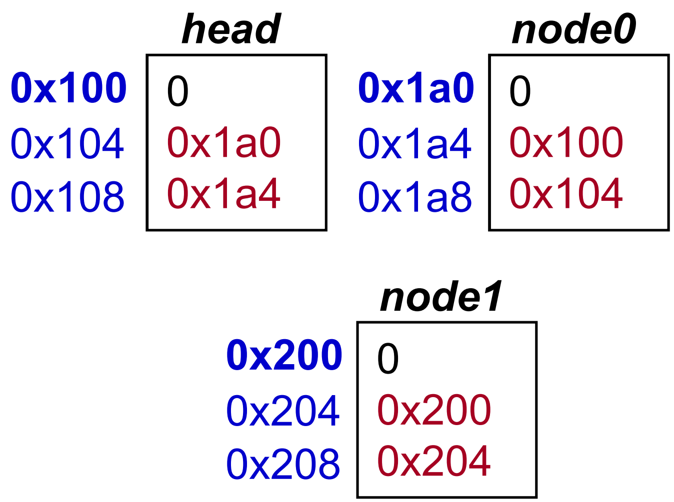
0x200	0
0x204	0x200
0x208	0x204

```
#define QINSERT_BEFORE(head, node, alist)\
  do {                                              \
     *(head)->alist.prev = (node);                  \
      (node)->alist.prev = (head)->alist.prev;      \
      (head)->alist.prev  = &(node)->alist.next;    \
      (node)->alist.next = (head);                  \
  } while (/* */0)
```

QINSERT_BEFORE(head, node1, alist);

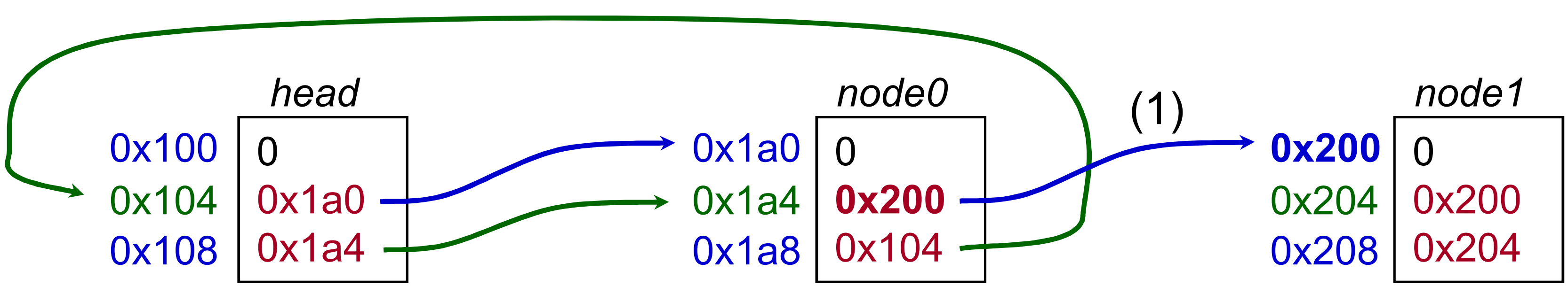


Adding a Third Node

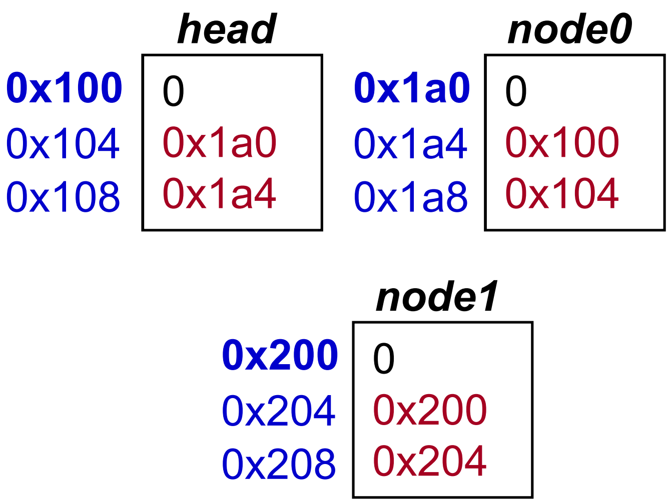



```
#define QINSERT_BEFORE(head, node1, alist)\
  do {                                                    \
(1) *(head)->alist.prev = (node1);                        \
      (node1)->alist.prev = (head)->alist.prev;           \
      (head)->alist.prev  = &(node1)->alist.next;         \
      (node1)->alist.next = (head);                       \
  } while (/* */0)
```

QINSERT_BEFORE(head, node1, alist);

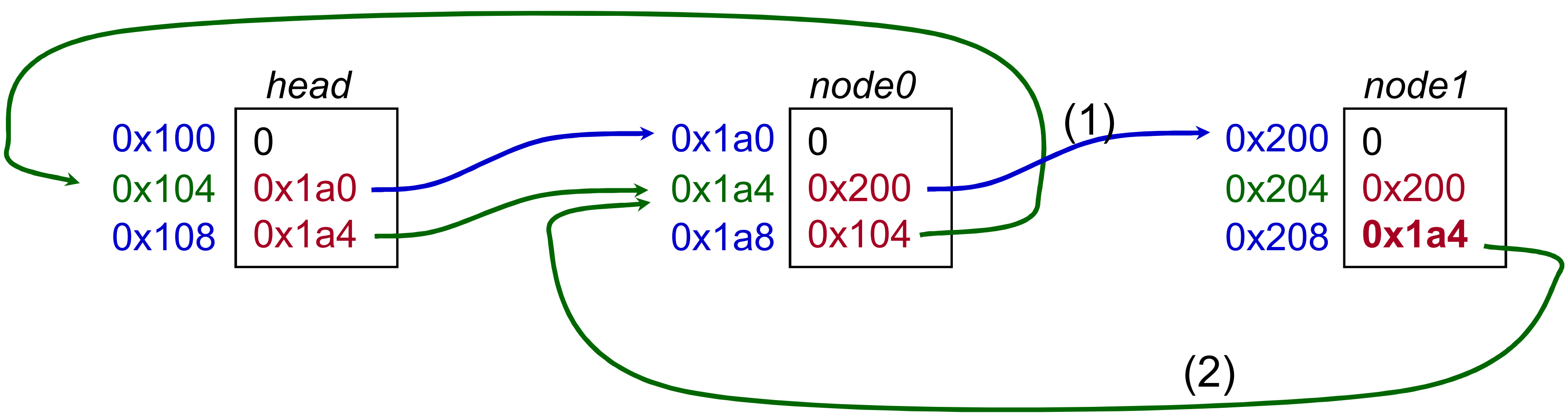


Adding a Third Node

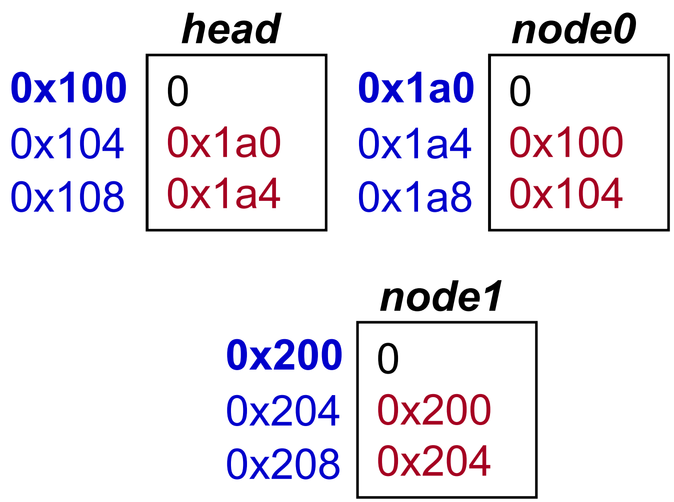



```
#define QINSERT_BEFORE(head, node1, alist)\
  do {                                                    \
      *(head)->alist.prev = (node1);                      \
 (2)  (node1)->alist.prev = (head)->alist.prev;           \
      (head)->alist.prev  = &(node1)->alist.next;         \
      (node1)->alist.next = (head);                       \
  } while (/* */0)
```

QINSERT_BEFORE(head, node1, alist);

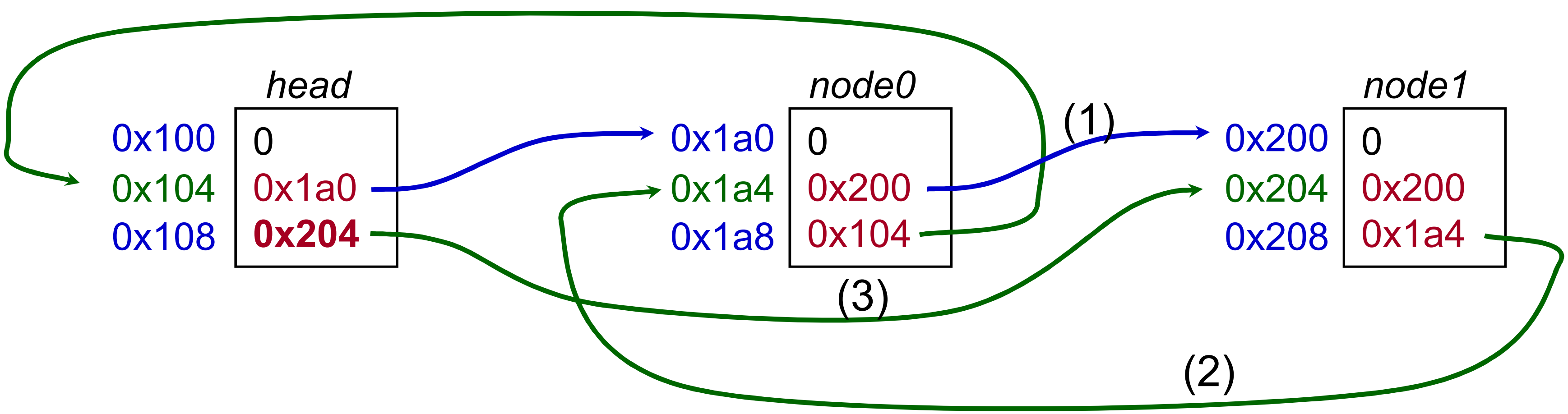


Adding a Third Node




```
#define QINSERT_BEFORE(head, node1, alist)\
  do {                                                    \
(1) *(head)->alist.prev = (node1);                        \
(2)  (node1)->alist.prev = (head)->alist.prev;            \
(3)  (head)->alist.prev  = &(node1)->alist.next;          \
     (node1)->alist.next = (head);                        \
  } while (/* */0)
```

QINSERT_BEFORE(head, node1, alist);



Adding a Third Node

head

0x100	0
0x104	0x1a0
0x108	0x1a4

node0

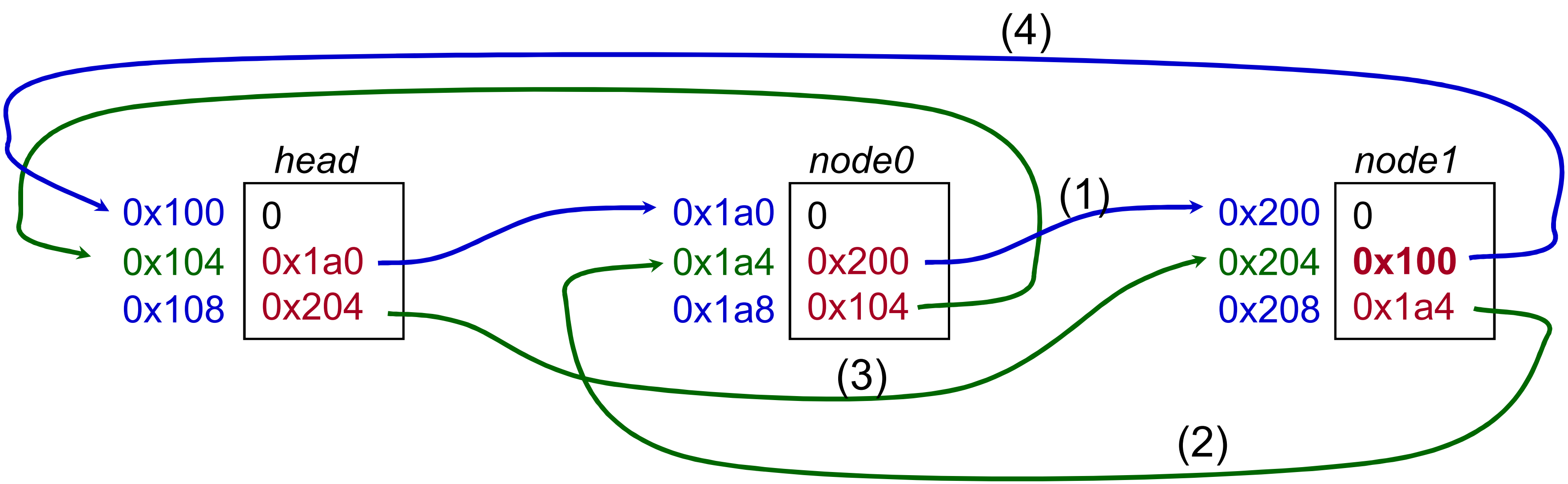
0x1a0	0
0x1a4	0x100
0x1a8	0x104

node1

0x200	0
0x204	0x200
0x208	0x204

```
#define QINSERT_BEFORE(head, node1, alist)\
  do {                                             \
(1) *(head)->alist.prev = (node1);                 \
(2)  (node1)->alist.prev = (head)->alist.prev;     \
(3)  (head)->alist.prev  = &(node1)->alist.next;   \
(4)  (node1)->alist.next = (head);                 \
  } while (/* */0)
```

QINSERT_BEFORE(head, node1, alist);



Removing a Node

head

0x100	0
0x104	0x1a0
0x108	0x204

node0

0x1a0	0
0x1a4	0x200
0x1a8	0x104

node1

0x200	0
0x204	0x100
0x208	0x1a4

```
#define QREMOVE(node, alist)                                   \
  do {                                                         \
    (1) *((node)->alist.prev) = (node)->alist.next;            \
    (2) ((node)->alist.next)->alist.prev = (node)->alist.prev;\
    (3) (node)->alist.next = (node);                           \
    (4) (node)->alist.prev = &((node)->alist.next);            \
  } while ( /* */ 0)
```

QREMOVE(node0, alist);

head

0x100	0
0x104	**??**
0x108	**??**

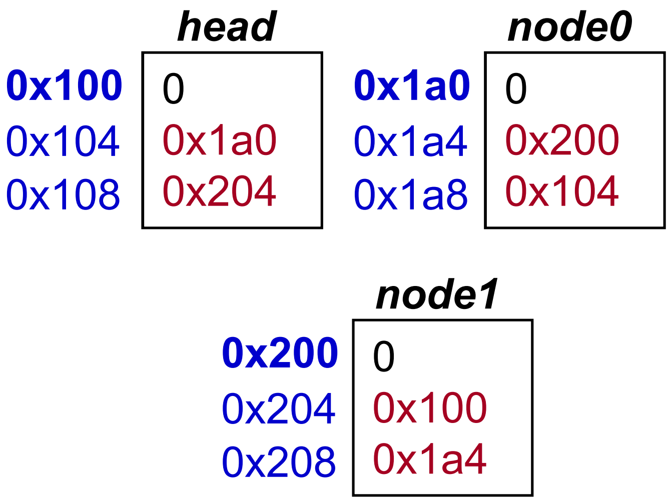
node0

0x1a0	0
0x1a4	**??**
0x1a8	**??**

node1

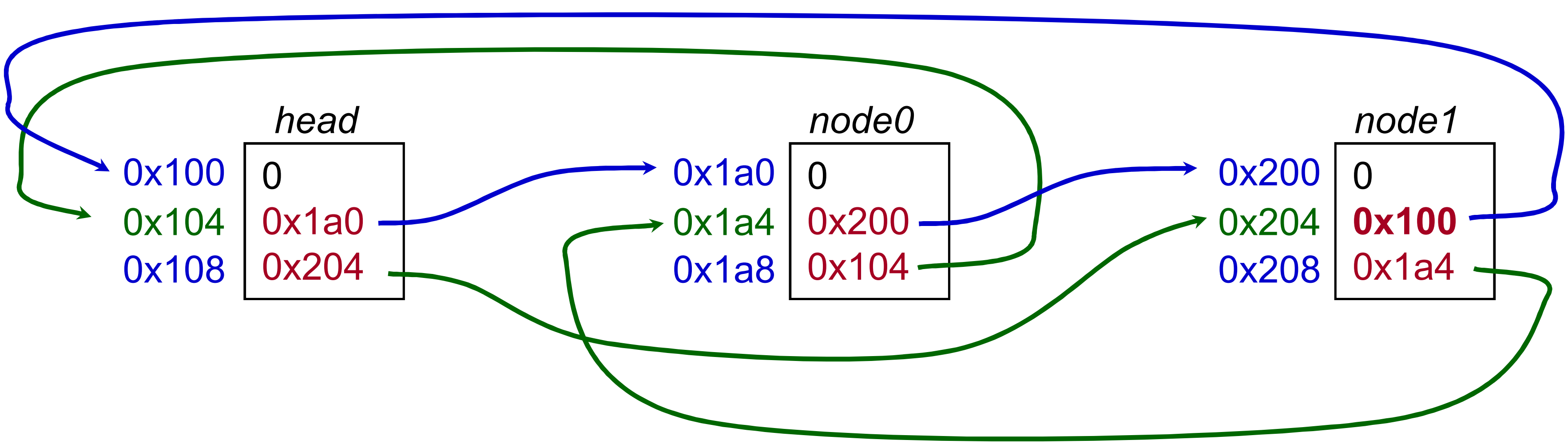
0x200	0
0x204	**??**
0x208	**??**

Removing a Node

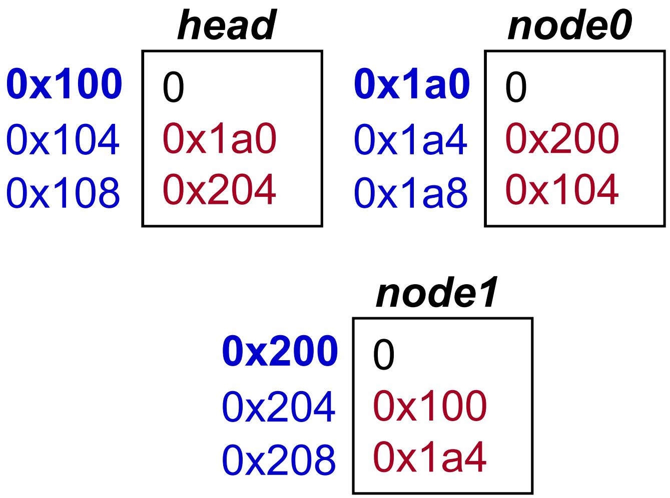



```
#define QREMOVE(node, alist)                                   \
  do {                                                         \
    *((node)->alist.prev) = (node)->alist.next;                \
     ((node)->alist.next)->alist.prev = (node)->alist.prev;\
     (node)->alist.next = (node);                              \
     (node)->alist.prev = &((node)->alist.next);               \
  } while ( /* */ 0)
```

QREMOVE(node0, alist);

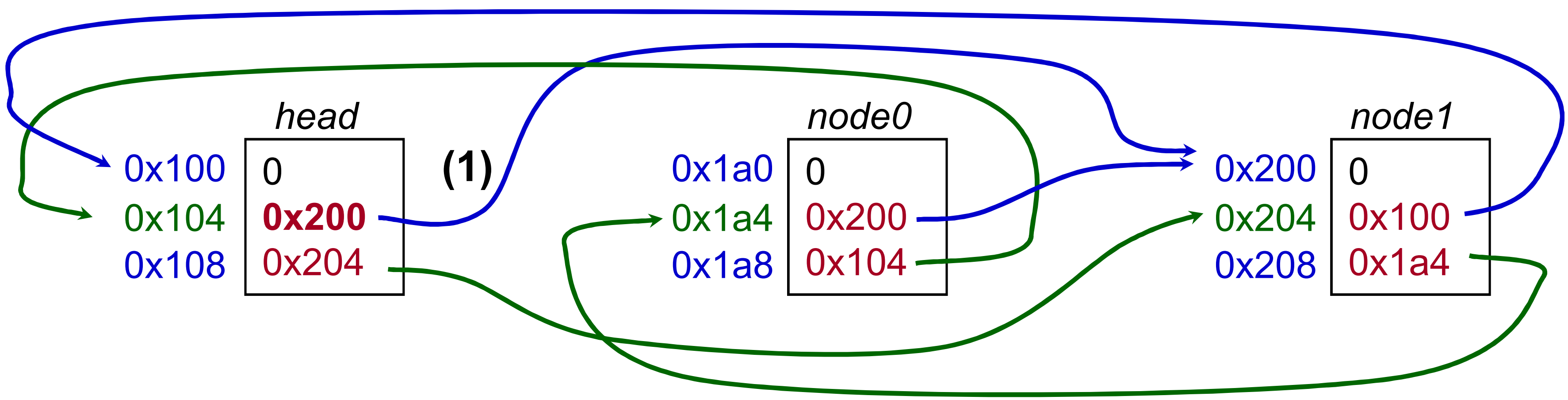


Removing a Node




```
#define QREMOVE(node0, alist)                                   \
  do {                                                          \
    (1) *((node0)->alist.prev) = (node0)->alist.next;           \
        ((node0)->alist.next)->alist.prev = (node0)->alist.prev;\
        (node0)->alist.next = (node0);                          \
        (node0)->alist.prev = &((node0)->alist.next);           \
  } while ( /* */ 0)
```

QREMOVE(node0, alist);



Removing a Node

head

0x100	0
0x104	0x1a0
0x108	0x204

node0

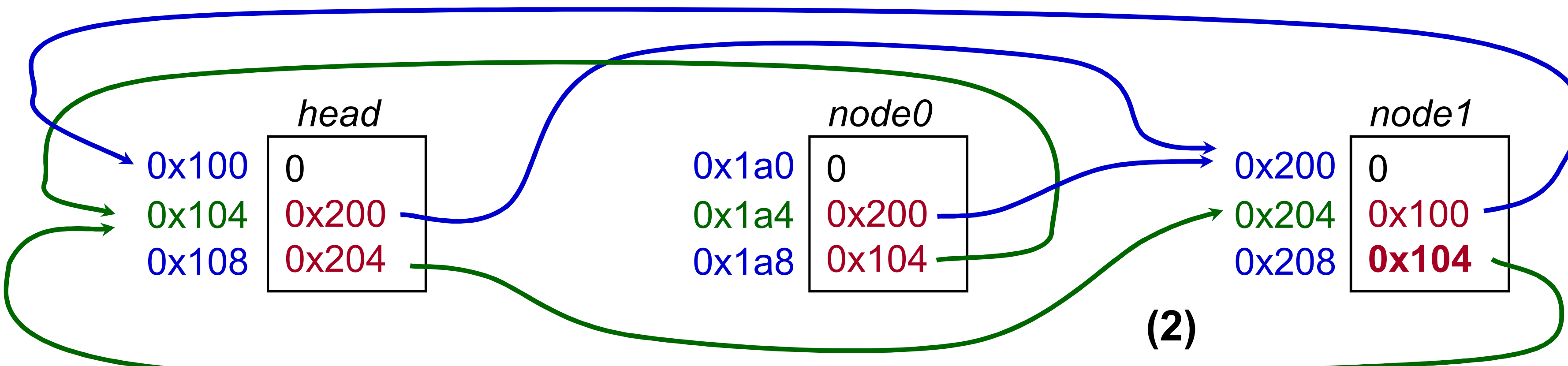
0x1a0	0
0x1a4	0x200
0x1a8	0x104

node1

0x200	0
0x204	0x100
0x208	0x1a4

```
#define QREMOVE(node0, alist)                              \
  do {                                                     \
        *((node0)->alist.prev) = (node0)->alist.next;      \
    (2) ((node0)->alist.next)->alist.prev = (node0)->alist.prev;\
        (node0)->alist.next = (node0);                     \
        (node0)->alist.prev = &((node0)->alist.next);      \
  } while ( /* */ 0)
```

QREMOVE(node0, alist);



Removing a Node

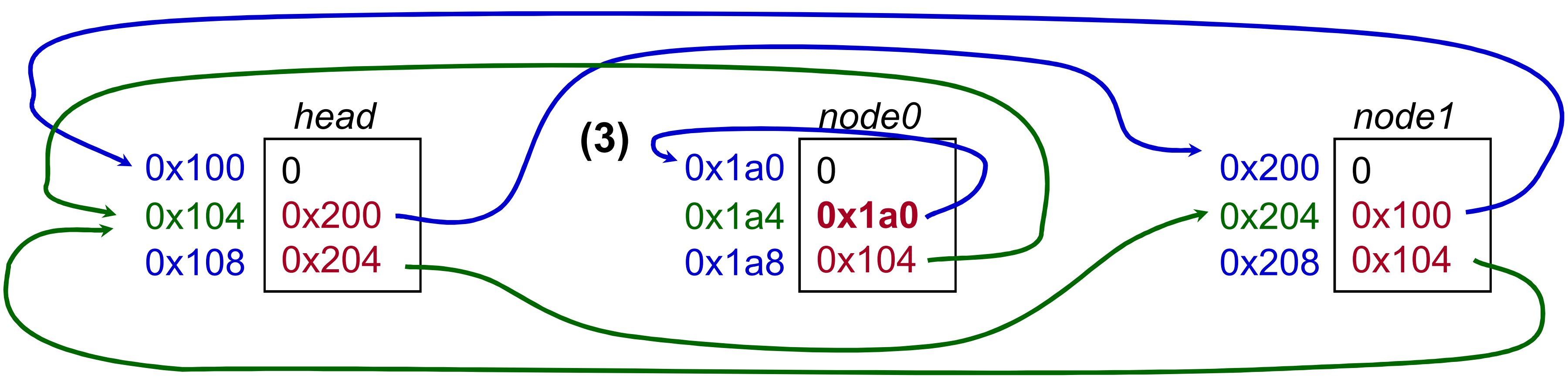
	head
0x100	0
0x104	0x1a0
0x108	0x204

	node0
0x1a0	0
0x1a4	0x200
0x1a8	0x104

	node1
0x200	0
0x204	0x100
0x208	0x1a4

```
#define QREMOVE(node0, alist)                                  \
  do {                                                         \
        *((node0)->alist.prev) = (node0)->alist.next;          \
         ((node0)->alist.next)->alist.prev = (node0)->alist.prev;\
    (3) (node0)->alist.next = (node0);                         \
        (node0)->alist.prev = &((node0)->alist.next);          \
  } while ( /* */ 0)
```

QREMOVE(node0, alist);



Removing a Node

head

0x100	0
0x104	0x1a0
0x108	0x204

node0

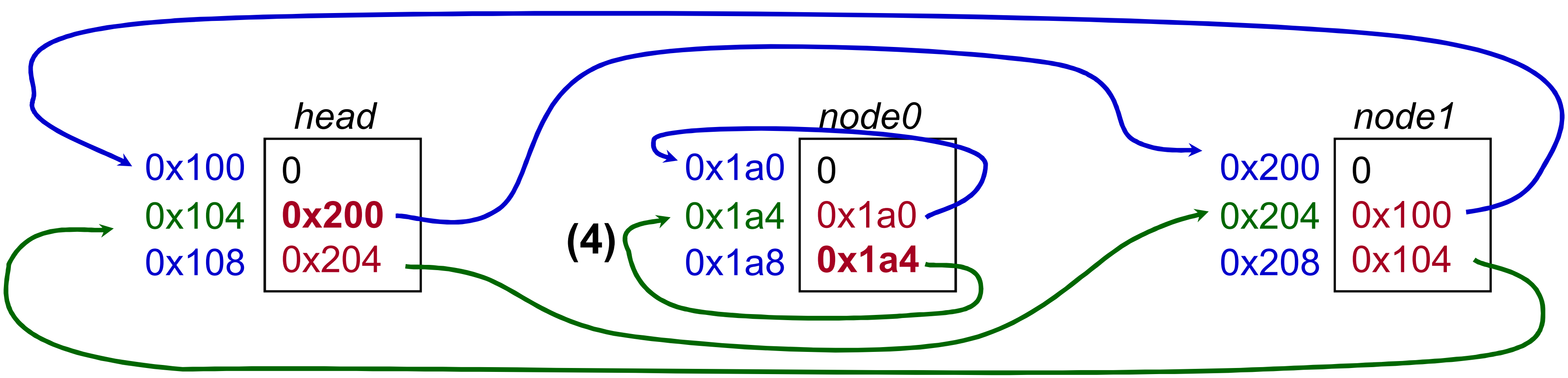
0x1a0	0
0x1a4	0x200
0x1a8	0x104

node1

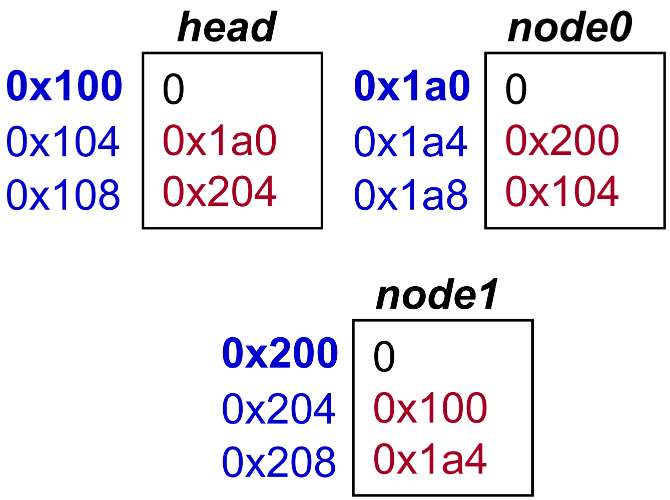
0x200	0
0x204	0x100
0x208	0x1a4

```
#define QREMOVE(node0, alist)                                   \
  do {                                                          \
        *((node0)->alist.prev) = (node0)->alist.next;           \
        ((node0)->alist.next)->alist.prev = (node0)->alist.prev;\
        (node0)->alist.next = (node0);                          \
    (4) (node0)->alist.prev = &((node0)->alist.next);           \
  } while ( /* */ 0)
```

QREMOVE(node0, alist);

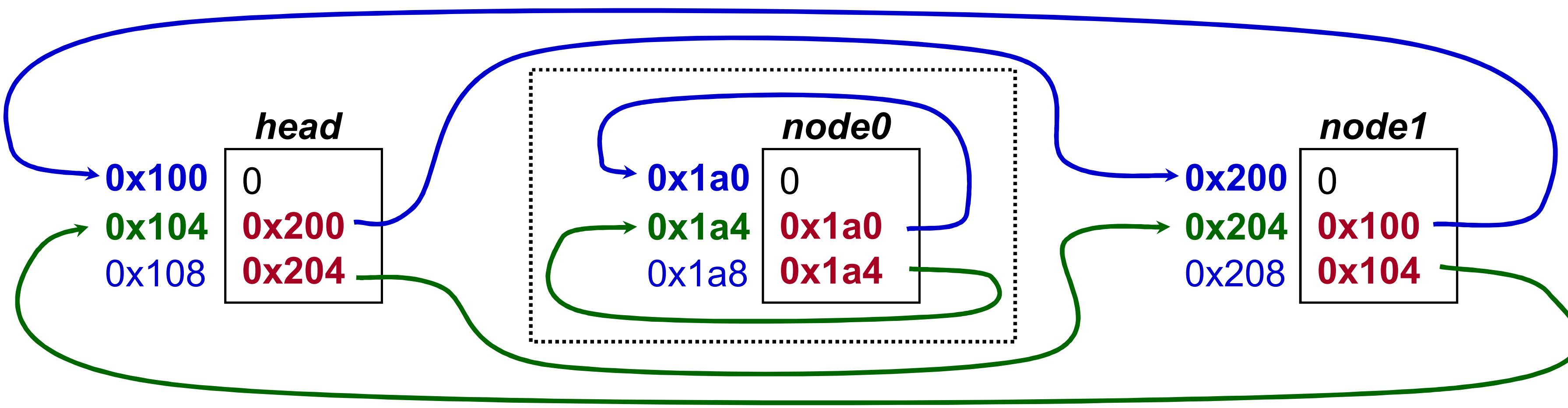


Solution to Removing a Node




```
#define QREMOVE(node, alist)                                  \
  do {                                                        \
    (1) *((node)->alist.prev) = (node)->alist.next;           \
    (2) ((node)->alist.next)->alist.prev = (node)->alist.prev;\
    (3) (node)->alist.next = (node);                          \
    (4) (node)->alist.prev = &((node)->alist.next);           \
  } while ( /* */ 0)
```

QREMOVE(node0, alist);



Functions

- Always use function prototypes

```
int myfunc (char *, int, struct MyStruct *);
int myfunc_noargs (void);
void myfunc_noreturn (int i);
```

- C and C++ are *call by value*, copy of parameter passed to function
  - C++ permits you to specify pass by reference
  - if you want to alter the parameter then pass a pointer to it (or use references in C++)
- If performance is an issue then use inline functions, generally better and safer than using a macro. Common convention
  - define prototype and function in header or *name*.i file
  - `static inline int myinfunc (int i, int j);`
  - `static inline int myinfunc (int i, int j) { ... }`

Basic Types and Operators

- Basic data types
  - Types: *char, int, float and double*
  - Qualifiers: *short, long, unsigned, signed, const*
- Constant: 0x1234, 12, “Some string”
- Enumeration:
  - Names in different enumerations must be distinct
  - ```
    enum WeekDay_t {Mon, Tue, Wed, Thur, Fri};
    enum WeekendDay_t {Sat = 0, Sun = 4};
    ```
- Arithmetic: +, -, *, /, %
  - prefix ++i or --i ; increment/decrement before value is used
  - postfix i++, i--; increment/decrement after value is used
- Relational and logical: <, >, <=, >=, ==, !=, &&, ||
- Bitwise: &, |, ^ (xor), <<, >>, ~(ones complement)
    ```

Operator Precedence (from "C a Reference Manual", 5th Edition)

Tokens	Operator	Class	Precedence	Associates
names, literals	simple tokens	primary	16	n/a
a[k]	subscripting	postfix		left-to-right
f(...)	function call	postfix		left-to-right
.	direct selection	postfix		left-to-right
->	indirect selection	postfix		left to right
++ --	increment, decrement	**postfix**		left-to-right
(*type*){*init*}	compound literal	postfix		left-to-right
++ --	increment, decrement	**prefix**	15	right-to-left
sizeof	size	unary		right-to-left
~	bitwise not	unary		right-to-left
!	logical not	unary		right-to-left
- +	negation, plus	unary		right-to-left
&	address of	unary		right-to-left
*	indirection (*dereference*)	unary		right-to-left

Tokens	Operator	Class	Precedence	Associates
(*type*)	casts	unary	14	right-to-left
* / %	multiplicative	binary	13	left-to-right
+ -	additive	binary	12	left-to-right
<< >>	left, right shift	binary	11	left-to-right
< <= > >=	relational	binary	10	left-to-right
== !=	equality/ineq.	binary	9	left-to-right
&	bitwise and	binary	8	left-to-right
^	bitwise xor	binary	7	left-to-right
|	bitwise or	binary	6	left-to-right
&&	logical and	binary	5	left-to-right
||	logical or	binary	4	left-to-right
?:	conditional	ternary	3	right-to-left
= += -= *= /= %= &= ^= |= <<= >>=	assignment	binary	2	right-to-left
,	sequential eval.	binary	1	left-to-right

Structs and Unions

- structures
  - `struct MyPoint {int x, int y};`
  - `typedef struct MyPoint MyPoint_t;`
  - `MyPoint_t point, *ptr;`
  - `point.x = 0;point.y = 10;`
  - `ptr = &point; ptr->x = 12; ptr->y = 40;`
- unions
  - `union MyUnion {int x; MyPoint_t pt; struct {int 3; char c[4]} S;};`
  - `union MyUnion x;`
  - Can only use one of the elements. Memory will be allocated for the largest element

Conditional Statements (if/else)

```
if (a < 10)
  printf("a is less than 10\n");
else if (a == 10)
  printf("a is 10\n");
else
  printf("a is greater than 10\n");
```

- If you have compound statements then use brackets (blocks)
  - ```
    if (a < 4 && b > 10) {
      c = a * b; b = 0;
      printf("a = %d, a\'s address = 0x%08x\n", a, (uint32_t)&a);
    } else {
      c = a + b; b = a;
    }
    ```
- These two statements are equivalent:
  - `if (a) x = 3; else if (b) x = 2; else x = 0;`
  - `if (a) x = 3; else {if (b) x = 2; else x = 0;}`
- Is this correct?
  - ```
    if (a) x = 3; else if (b) x = 2;
    else (z) x = 0; else x = -2;
    ```

Conditional Statements (switch)

```
int c = 10;
switch (c) {
  case 0:
    printf("c is 0\n");
    break;
  ...
  default:
    printf("Unknown value of c\n");
    break;
}
```

- What if we leave the break statement out?
- Do we need the final break statement on the default case?

Loops

```
for (i = 0; i < MAXVALUE; i++) {
        dowork();
    }
while (c != 12) {
        dowork();
    }
do {
        dowork();
    } while (c < 12);
```

- flow control
  - **break** – exit innermost loop
  - **continue** – perform next iteration of loop
- Note, all these forms permit one statement to be executed. By enclosing in brackets we create a block of statements.

Building your program

- For all labs and programming assignments:
  - you must supply a make file
  - you must supply a README file that describes the assignment and results. This must be a text file, no MS word.
  - of course the source code and any other libraries or utility code you used
  - you may submit plots, they must be postscript or pdf

make and Makefiles, Overview

- Why use make?
  - convenience of only entering compile directives once
  - make is smart enough (with your help) to only compile and link modules that have changed or which depend on files that have changed
  - allows you to hide platform dependencies
  - promotes uniformity
  - simplifies my (and hopefully your) life when testing and verifying your code
- A makefile contains a set of rules for building a program

```
target ... : prerequisites ...
        command
        ...
```

- Static pattern rules.
  - each target is matched against target-pattern to derive stem which is used to determine prereqs (see example)

```
targets ... : target-pattern : prereq-patterns ...
  command
  ...
```

Makefiles

- Defining variables
```
MyOPS := -DWTH
MyDIR ?= /home/fred
MyVar   = $(SHELL)
```
- Using variables
```
MyFLAGS := $(MyOPS)
```
- Built-in Variables
  - $@ = filename of target
  - $< = name of the first prerequisites
- Patterns
  - use % character to determine stem
  - foo.o matches the pattern %.o with foo as the stem.
  - foo.o moo.o : %.o : %.c # says that foo.o depends on foo.c and moo.o depends on moo.c

Example Makefile for wulib

Makefile.inc

```
# Makefile.inc
# Contains common definitions

MyOS              := $(shell uname -s)
MyID              := $(shell whoami)
MyHost            := $(shell hostname)
WARNSTRICT        := -W \
                     -Wstrict-prototypes
\
                    -Wmissing-prototypes
WARNLIGHT         := -Wall
WARN              := ${WARNLIGHT}
ALLFLGS           := -D_GNU_SOURCE \
                    -D_REENTRANT \
                    -D_THREAD_SAFE

APPCFLGS          = $(ALLFLGS) \
                    $(WARN)

WUCC              := gcc
WUCFLAGS          := -DMyOS=$(MyOS) \
                    $(OSFLAGS) \
                    $(ALLFLGS) $(WARN)

WUINCLUDES        :=
WULIBS            := -lm

ifeq (${MyOS), SunOS)
OSLIBS+= -lrt
endif
```

Makefile

```
# Project specific
include ../Makefile.inc
INCLUDES     = ${WUINCLUDES} -I.
LIBS         = ${WILIBS} ${OSLIBS}
CFLAGS       = ${WUCLFAGS} -DWUDEBUG
CC           = ${WUCC}

HDRS         := util.h
CSRCS        := testapp1.c testapp2.c
SRCS         := util.c callout.c
COBJS        = $(addprefix ${OBJDIR}/, \
                             $(patsubst %.c,%.o,$(CSRCS)))
OBJS         = $(addprefix ${OBJDIR}/, \
                             $(patsubst %.c,%.o,$(SRCS)))
CMDS         = $(addprefix ${OBJDIR}/, $(basename $(CSRCS)))

all :   $(OBJDIR) $(CMDS)

install : all

$(OBJDIR) :
             mkdir $(OBJDIR)

$(OBJS)  $(COBJS) :  ${OBJDIR}/%.o :  %.c  $(HDRS)
             ${CC} ${CFLAGS} ${INCLUDES} -o $@ -c $<

$(CMDS) : ${OBJDIR}/% : ${OBJDIR}/%.o $(OBJS)
             ${CC} ${CFLAGS} -o $@ $@.o ${LIBS}
             chmod 0755 $@

clean :
             /bin/rm -f $(CMDS) $(OBJS)
```

Project Documentation

- README file structure
  - ***Section A***: *Introduction*
    describe the project, paraphrase the requirements and state your understanding of the assignments value.
  - ***Section B***: *Design and Implementation*
    List all files turned in with a brief description for each. Explain your design and provide simple psuedo-code for your project. Provide a simple flow chart of you code and note any constraints, invariants, assumptions or sources for reused code or ideas.
  - ***Section C***: *Results*
    For each project you will be given a list of questions to answer, this is where you do it. If you are not satisfied with your results explain why here.
  - ***Section D***: *Conclusions*
    What did you learn, or not learn during this assignment. What would you do differently or what did you do well.

Attacking a Project

- *Requirements and scope*: Identify specific requirements and or goals. Also note any design and/or implementation environment requirements.
  - knowing when you are done, or not done
  - estimating effort or areas which require more research
  - programming language, platform and other development environment issues
- *Approach*: How do you plan to solve the problem identified in the first step. Develop a prototype design and document. Next figure out how you will verify that you did satisfy the requirements/goals. Designing the tests will help you to better understand the problem domain and your proposed solution
- *Iterative development*: It is good practice to build your project in small pieces. Testing and learning as you go.
- *Final Touches*: Put it all together and run the tests identified in the approach phase. Verify you met requirements. Polish you code and documentation.
- *Turn it in*: