ECE 264 Reference Sheet – Fall 2016

v0.99.5 (12/4/2016)

command line

purpose	*command*	*flags*	*example(s)*
view file(s)	**ls** [-l] [*path…*]	-l → verbose	ls *.c
change directory	**cd** *directory*		cd ps1
make directory	**mkdir** [-m *permissions*] *directory*	-m → set permissions	mkdir tempdir
remove directory	**rmdir** *directory*		rmdir tempdir
delete (remove) files	**rm** [-R] [-f] *path…*	-r → recursive -f → force (remove or overwrite) without asking	rm mytester
copy files	**cp** [-R] [-f] *from…* *to*		cp –R * ../ps1 backup 5
move or rename files	**mv** *from…* *to*		mv
view processes	**ps** [uxw]	uxw→ detailed output	ps auxw
hex dump	**xxd** [-g *# of bytes*]	-g → group by *# of bytes*	
edit file	**vim** [-p] *path…*	-p → open files in tabs	vim –p *.c *.h
compile	**gcc** [-o *executable*] *path…*	-o → output executable	gcc -o ps1 ps1.c
get starter files	**264get** *asg*	*asg* is the short name of the assignment (e.g., "hw01")	264get hw01
pre-test submission	**264test** *asg*		264test hw01
submit	**264submit** *asg* *path…*	*path…* is the file(s) or "*" for all	264submit hw01 *

vim

motion *within line*	**h** ←	**l** →	**0** to beginning of line	**$** to end of line	**^** to first non-blank in line	**w** to beginning of next word	**e** to end of this word	**b** to beginning of this or last word
motion *between lines*	**k** ↑	**j** ↓	**gg** to beginning of file	**G** to end of file	*line#* **G** line number	**%** to matching ({ [<	**m***a-z* mark position	**'***a-z* go to mark
motion *search*	***** find word, forward	**#** find word, backward	**/***pattern* find pattern, forward	*pattern*: . any char; \d number; \w alphanum.; * 0 or more		**n** to next match	**N** to previous match	**:noh** clear search highlighting
action *current line*	**dd** delete line (cut)	**cc** change line	**yy** yank line (copy)	**>>** indent line	**<<** dedent line	**==** indent code line	**gugu** lowercase line	**gUgU** Uppercase line
action *by motion*	**d***motion* delete (cut)	**c***motion* change	**y***motion* yank (copy)	**>***motion* indent	**<***motion* dedent	**=***motion* indent code	**gu***motion* lowercase	**gU***motion* Uppercase
action *add text*	**i** insert before this character	**I** Insert before line beginning	**a** append after this character	**A** Append after line end	**o** open line below	**O** Open line above	**p** put (paste) text here/below	**P** Put (paste) text before/above
other *visual, undo, …*	**v** visual select	**V** visual select line	**u** undo last action	**^R** redo last undone action	**.** repeat last action	**q***a-z* record quick macro	**q** stop recording quick macro	**@***a-z* play quick macro
commands *"ex" mode*	**:w** write (save) file	**:e** *file* edit (open) file	**:tabe** *file* tab: edit file	**:split** split window	**:%s/***pattern***/***text***/gc** replace *pattern* with *text*		**:h** *topic/cmd* help	**:q** quit Vim

Press **Esc** to return to Normal mode. | Most normal mode commands can be repeated by preceding with a number (e.g., **3dd** to delete 3 lines).

gdb

Start

In bash: **gdb** [--tui] *file*
quit
set args [*arglist…*]

Breakpoints

break *[file]:function* | *[file]:line#*
clear *[file]:function* | *[file]:line#*
delete [*breakpoint#*]
info breakpoints

Watchpoints

watch *variable*
awatch *variable*
rwatch *variable*
info watchpoints

Automatic display

info display
display *expression*
undisplay [*expression#*]

Explore the stack frame

backtrace [full] [n]
down *# toward current frame*
frame [*frame#*]
info args
info frame
info locals
list *function* | *line#[,line#]*
up *# toward main()*
whatis *variable*

Controlling execution

continue
finish
jump *[file]:function* | *[file]:line#*
next
return [*expr*]
run [*arguments…*]
set variable *var* = *expr*
step
until *[file]:function* | *[file]:line#*

Reverse debugging

record
reverse-next
reverse-step *# and so on…*

View variables and memory

print[/*format*] *expression*

- *format* ∈ d *(decimal)*, x *(hex)*, t *(binary)*, f *(float)*, c *(char.)*, u *(unsigned decimal)*, o *(octal)*, a *(hex address)*, z *(hex, 0-padded)*
- *expression*: a C expression

x/*# of bytes* *unit* *format*

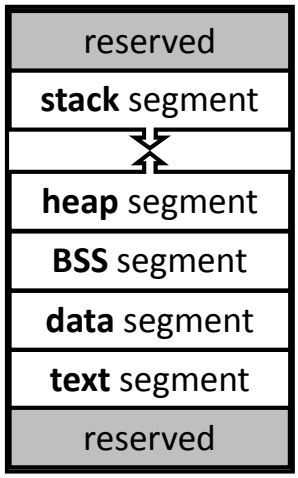
- *# of bytes*: how much to view
- *format*: same as p, or s *(string)*
- *unit* ∈ b *(1 byte)*, h *(2 bytes)*, w *(4 bytes)*, g *(8 bytes)*

For more info: **help** *command*

Underlined letters indicate shortcuts (e.g., n for next, rn for reverse-next, etc.) | Brackets denote parameters that are optional.

course web site: **engineering.purdue.edu/ece264/16au** —or— aq.gs/264

memory




```
                                  Your code, compiled binary ····· text segment
void oat(char pie) {  ··········· parameters ····· stack segment
  char ham;  ····· local variable ····· stack segment
  char bun[4];  ····· statically-allocated array ····· stack segment
  char* ice =  ····· local variable (even an address) ····· stack segment
    "pop";  ····· string literals ····· data segment, read-only
  char* yam =  ····· local variable (even an address) ····· stack segment
    malloc(sizeof(*yam));  ··· dynamic allocation block ····· heap segment
  static char egg = 1;  ····· static variable, initialized ····· data segment, read-write
  static char nut;  ····· static variable, uninitialized ····· BSS segment
  free(yam);
}
char _g_jam = 2;  ····· global variable, initialized ····· data segment, read-write
char _g_tea;  ····· global variable, uninitialized ····· BSS segment
```

addresses (pointers)

```
int a = 10;   // "a gets 10"

int* b;       // "b is an address of an int"
b = &a;       // "b gets the address of a"

int c = *b;   // "c gets the value at b"

int* d = malloc(sizeof(*d));
              // "d gets the address of a
              // new allocation block
              // sufficient for 1 int"

*d = 10;      // "store 10 at address d"
```

All (a, *b, c, *d) equal 10.

arrays

```
int a1[2];
a1[0] = 7;
a1[1] = 8;

int  a2[]  = {7, 8};

int  a3[2] = {7, 8};

int* a4    = {7, 8};

int* a5 = malloc(
   sizeof(*a5) * 2);
a5[0] = 7;
a5[1] = 8;
```

All (a1…a5) contain {7, 8}.

strings

```
char s1[3];
s1[0] = 'H';  // 'H' == 72
s1[1] = 'i';  // 'i' 1== 105
s1[2] = '\0'; // '\0' == 0
char s2[] = {'H', 'i', '\0'};
char s3[] = "Hi";
char* s4  = "Hi";
char s5[] = {72, 105, 0};
char s6[] = {0x48, 0x69, 0x00};
char s7[] = "\x48\x69";
char* s8 = malloc(sizeof(*s8)*3);
strcpy(s8, "Hi");
char* s9 = strdup("Hi");
```

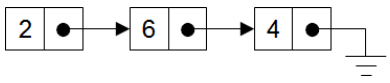
All (s1…s9) contain the string "Hi".

structs

	Basic syntax	*Basic syntax + typedef alias*	*Concise syntax (popular)*
Define struct type	`struct Point { int x, y; };`	`struct _P { int x, y; }; typedef struct _P Point;`	`typedef struct { int x, y; } Point;`
Declare + initialize	`struct Point p = { .x = 10, .y = 20 };`	`Point p = { .x = 10, .y = 20 };`	
Declare object	`struct Point p;`		`Point p;`
Initialize fields	`p.x = 10;  p.y = 20;`		
Access fields	`int w = p.x;` *// **p.x** is the same as **(&p) -> x***		
Address (pointer)	`struct Point* a_p = &p;`		`Point* p = &p;`
Access via address	`int w = a_p -> x;` *// **a_p -> x** is the same as **(*a_p).x***		

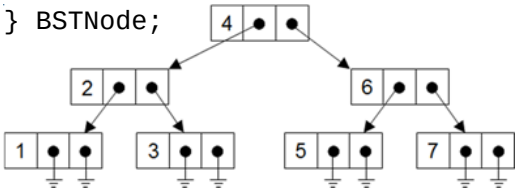
linked lists

```
typedef struct _Node {
  int value;
  struct _Node* next;
} Node;
```



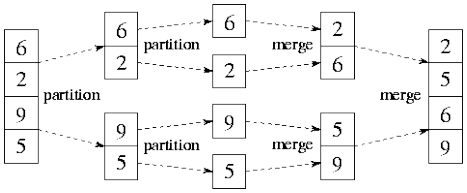
binary search tree (BST)

```
typedef struct _BSTNode {
  int value;
  struct _BSTNode* left;
  struct _BSTNode* right;
} BSTNode;
```



merge sort

Step 1: Partition the list in half.
Step 2: Merge sort each half.
Step 3: Merge the two sorted halves into a single sorted list.



ASCII table

Dec	Hex	Char	Dec	Hex	Char	Dec	Hex	Char	Dec	Hex	Char	Dec	Hex	Char	Dec	Hex	Char	Dec	Hex	Char	Dec	Hex	Char
32	0x20	' '	44	0x2c	,	56	0x38	8	68	0x44	D	80	0x50	P	92	0x5c	\	104	0x68	h	116	0x74	t
33	0x21	!	45	0x2d	-	57	0x39	9	69	0x45	E	81	0x51	Q	93	0x5d	]	105	0x69	i	117	0x75	u
34	0x22	"	46	0x2e	.	58	0x3a	:	70	0x46	F	82	0x52	R	94	0x5e	^	106	0x6a	j	118	0x76	v
35	0x23	#	47	0x2f	/	59	0x3b	;	71	0x47	G	83	0x53	S	95	0x5f	_	107	0x6b	k	119	0x77	w
36	0x24	$	48	0x30	0	60	0x3c	<	72	0x48	H	84	0x54	T	96	0x60	`	108	0x6c	l	120	0x78	x
37	0x25	%	49	0x31	1	61	0x3d	=	73	0x49	I	85	0x55	U	97	0x61	a	109	0x6d	m	121	0x79	y
38	0x26	&	50	0x32	2	62	0x3e	>	74	0x4a	J	86	0x56	V	98	0x62	b	110	0x6e	n	122	0x7a	z
39	0x27	'	51	0x33	3	63	0x3f	?	75	0x4b	K	87	0x57	W	99	0x63	c	111	0x6f	o	123	0x7b	{
40	0x28	(	52	0x34	4	64	0x40	@	76	0x4c	L	88	0x58	X	100	0x64	d	112	0x70	p	124	0x7c	|
41	0x29	)	53	0x35	5	65	0x41	A	77	0x4d	M	89	0x59	Y	101	0x65	e	113	0x71	q	125	0x7d	}
42	0x2a	*	54	0x36	6	66	0x42	B	78	0x4e	N	90	0x5a	Z	102	0x66	f	114	0x72	r	126	0x7e	~
43	0x2b	+	55	0x37	7	67	0x43	C	79	0x4f	O	91	0x5b	[	103	0x67	g	115	0x73	s	127	0x7f	DEL

preprocessor

```
#define    #elif      #if        #pragma    __DATE__   __FILE__   __TIME__
#include   #end       #ifdef     pack(1)    __FILE__   __LINE__   #macro   (stringify)
```

files and streams

```
FILE*   fopen(const char* filename,
        const char* mode)
int     fputc(int c, FILE* stream)
int     fprintf(FILE* stream,
        const char* fmt, ...)
int     fseek(FILE* stream, long offset,
        int whence)
long    ftell(FILE* stream)
int     fgetc(FILE* stream)
char*   fgets(char* buf, int n, FILE* stream)
int     feof(FILE *stream)
int     ferror(FILE* stream)
int     fclose(FILE* stream)
size_t  fread(void* dest, size_t size,
        size_t count, FILE* stream)
size_t  fwrite(const void* src, size_t size,
        size_t count, FILE* stream)
FILE*   stderr
FILE*   stdout
FILE*   stdin
```

printf codes

%d	decimal
%x	hex
%c	character
%p	address
%s	string
%zd	size_t

integer constants

65	decimal
0x41	hex
0101	octal
'A'	character
'\0'	null terminator
NULL	null address

bitwise operators

|	bitwise or	0b1001 **|** 0b0011 == 0b1011
&	bitwise and	0b1001 **&** 0b0011 == 0b0001
^	bitwise xor	0b1001 **^** 0b0011 == 0b1010
~	bitwise not	**~** 0b00001111 == 0b11110000
>>	bitshift right	0b00001111 **>>** 2 == 0b00000011
<<	bitshift left	0b00001111 **<<** 2 == 0b00111100

address operators

"address of *v*"	&*v*
"value at *a*"	*****a*
"write *v* at *a*"	*****a* = *v*

other operators

?: ternary	3>4 **?** 1 **:** 2 == 2
sizeof	**sizeof(***v***)** == 4

equivalence of address operators

```
  *a          a[i]        o.x         a -> x
   ⇳           ⇳           ⇳           ⇳
 a[0]        *(a+i)      (&o) -> x   (*a).x
```

effects of * and & on type

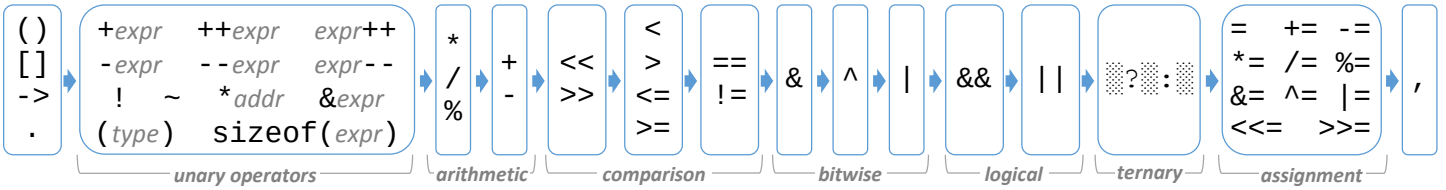
Adding * to a variable subtracts * from its type.

Example: If `n` is an `int**` ... then ...
`*n` is an `int*`
`**n` is an `int`

Adding & to a variable adds * to its type

Example: If a is an `int` ... then `&a` is an `int*`
If b is an `int*` ... then `&b` is an `int**`
If c is an `int**` ... then `&c` is an `int***`

precedence of operators



how to write bug-free code

- DRY – Don't Repeat Yourself
- Take time to learn your tools.
- Fix "broken windows" (e.g., warnings)
- Get enough sleep and nutrition.
- Eliminate distractions.
- Crash early, e.g., with assert(…).
- Use assert() to validate *your* code only.
- Free() where you malloc(), when possible.
- Design with contracts.

how to debug

- Use scientific method.
- Prove your assumptions.
- Re-read library documentation.
- Follow leads.
- The compiler isn't broken.
- Use the right debugging tool(s).
- Take notes to stop going in circles.
- Write test tools.
- Take a nap / walk / break.

memory faults / Valgrind error messages

To start Valgrind, run:
valgrind ./myprog

"Invalid write"

Buffer overflow – heap
```
int* a = malloc(
    4 * sizeof(*a) );
a[10] = 20; // !!!
```

Write dangling pointer – heap
```
int* a = malloc(…);
free(a);
a[0] = 1;
```

"Invalid read"

Buffer overread - heap
```
int* a = malloc(
    4 * sizeof(*a) );
int b = a[10]; // !!!
```

Read dangling pointer – heap
```
int* a = malloc(
    4 * sizeof(*a) );
free(a);
int b = a[0]; // !!!
```

Not detected by Valgrind

Buffer overread - stack
```
int a[4];
int b = a[10]; // !!!
```

Buffer overflow – stack
```
int a[4];
a[10] = 1; // !!!
```

Segmentation fault – crash

Writing at NULL with *
```
int* a = NULL;
*a = 10;
```

Writing at NULL with ->
```
Node* a = NULL;
a -> value = 10;
```

Writing at NULL with […]
```
int* array = NULL;
array[0] = 1;
```

Reading from NULL with *
```
int* a = NULL;
int b = *a;
```

Reading from NULL with ->
```
Node* p = NULL;
int b = p -> value;
```

Reading from NULL with […]
```
int* array = NULL;
int b = array[0];
```

Not detecting malloc() failure
```
int* a = malloc(
 10000000000000000);
*a = 1; // a is NULL
```

Stack overflow
```
void foo() {
  foo(); // !!!
}
```

Writing to read-only memory
```
char* s = "abc";
s[0] = 'A';
```

Calling va_arg too many times
```
while(a == 0) {
  b = va_arg(…);
}
```

"Conditional jump or move depends on uninitialised value(s)"

If with uninitialized condition
```
int a; // garbage!!!
if(a == 0) {
  // …
}
```

Loop with uninitialized condition
```
int a; // garbage!!!
while(a == 0) {
  // …
}
```

Switch with uninitialized condition
```
int a; // garbage!!!
switch(a) {
  // …
}
```

Printing unterminated string
```
char s[2];
s[0] = 'A'; // no '\0'
printf("%s", s);
```

"Use of uninitialized value"

Passing uninitialized value to fn
```
int a;
printf("%d", a);
```

"Syscall param … uninitialised byte(s)"

Return uninitialized value from fn
```
void foo() {
  int a;
  return a;
}
```

Write uninitialized value to file
```
char c;
fwrite(&c, 1, 3, stdout);
```

"Definitely lost" – leak

Lose address of block
```
void foo() {
  int* a = malloc(…);
} // !!!
```

"Indirectly lost" – leak

Lose address of address of block
```
void foo() {
  void** a =
malloc(…);
  *a = malloc(4);
} // !!!
```

"Still reachable" – leak

Address of block still in memory
```
int main() {
  static void* a;
  a = malloc(…);
  return EXIT_SUCCESS;
}
```

"Invalid free()"
"glibc … free"

Double free
```
int* a = malloc(…);
free(a);
free(a); // !!!
```

Free something not malloc'd
```
int a = 0;
free(&a);  // !!!
```

Free wrong part
```
int* a = malloc(…);
free(a + 3); // !!!
```

"silly arg (…) to malloc()"

Negative size to malloc(…)
```
void* a = malloc(-3);
free(a);
```

 | Author: Alexander J. Quinn (aq@purdue.edu) | Versions: This is v0.99.5 (12/4/2016) of this sheet. Information is based on Valgrind v3.8.1, gcc v6.1, gdb 7.2, vim v7.4, bash v4.1.2 | Credits: Debugging and bug-avoidance tips — loosely adapted from *The Pragmatic Programmer* – ©Andy Hunt & Dave Thomas | Merge sort image –*Designing and Building Parallel Programs* – ©Ian Foster