ECE 264 Reference Sheet – Spring 2019

v1.0.4 (4/29/2019)

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	rm mytester
copy files	cp [-r] [-f] from… to	-f → force (remove or overwrite) without asking	cp -r * backup/
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 hw02
pre-test submission	264test asg		264test hw02
submit	264submit asg path…	path… is the file(s) or "*" for all	264submit hw02 *.{c,h}

Submit often and early—even when you are just starting. To restore your earlier submission, type **264get --help** for further instructions.

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 or _ \s whitespace	**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).

pattern may also include: ▒***** (×0 or more) ▒**\+** (×1 or more) ▒**\=** (×0 or 1) \<▒\> (word) | To rename a variable: **:%s/\<▒\>/▒/gc**

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 line#

Reverse debugging

record

reverse-next

reverse-step # and so on…

View variables and memory

print[/format] expression

- expression : a C expression

x/[# of units][unit][format] address

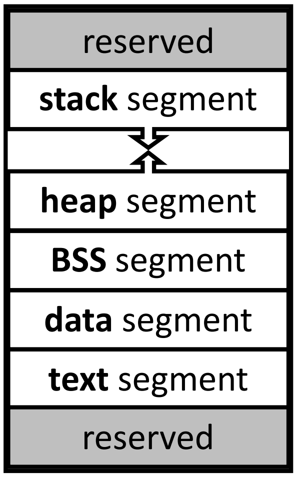
- # of units : how many units
- unit ∈ b (1 byte), h (2 bytes), w (4 bytes), g (8 bytes)
- format ∈ d (decimal), x (hex), s (string), f (float), c (character), u (unsigned decimal), o (octal), t (binary), z (zero-padded hex), a (address)

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/ece264/19sp** —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.

```
char (*a_f)(int, int) = f;
// "a_f is the address of function f(...) taking 2
// arguments (int, int) and returning char."
```

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");   // non-std
```

All (s1...s9) contain the string "Hi".

structs

	Basic syntax	*Basic syntax + typedef alias*	*Concise syntax (popular)*

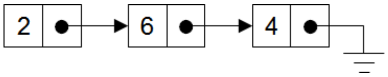
Define struct type	`struct Point {`
	`   int x, y;`
	`};`
		`struct _P {`
		`   int x, y;`
		`};`
		`typedef struct _P Point;`
			`typedef struct {`
			`   int x, y;`
			`} Point;`

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***		

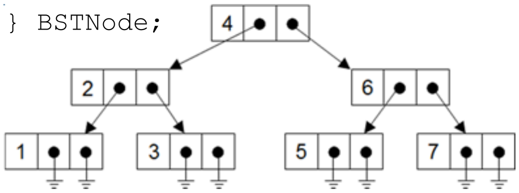
linked lists

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



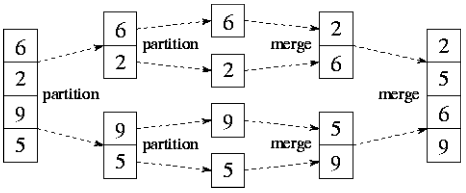
binary search tree (BST)

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

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

`()` `[]` `->` `.`	
`+`*expr* `++`*expr* *expr*`++` `-`*expr* `--`*expr* *expr*`--` `!` `~` `*`*addr* `&`*expr* `(`*type*`)` `sizeof(`*expr*`)`	*unary operators*
`*` `/` `%`	*arithmetic*
`+` `-`	
`<<` `>>`	*bit shift*
`<` `>` `<=` `>=`	*comparison*
`==` `!=`	
`&`	*bitwise*
`^`	
`|`	
`&&`	*logical*
`||`	
░?░:░	*ternary*
`=` `+=` `-=` `*=` `/=` `%=` `&=` `^=` `|=` `<<=` `>>=`	*assignment*
`,`	

how to write bug-free code

- DRY – Don't Repeat Yourself
- Learn to use your tools *well*.
- Fix "broken windows" (e.g., warnings)
- Get enough sleep and nutrition.
- Plan before you begin coding.
- 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

- Test hypotheses systematically.
- Take notes to stop going in circles.
- Verify your assumptions.
- Use the right debugging tool(s).
- Write test code.
- Take a nap / walk / break.
- Trust the compiler.
- Do not trust Stack Overflow, friends, etc.
- Do not make random changes.

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(
 100000000000000000);
*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);
```

| **Versions:** This is v1.0.4 (4/29/2019) of this sheet. Content refers to Vim v7.4, GDB v7.2, and Valgrind v3.8. **Credits:** Bug-avoidance tips inspired by *The Pragmatic Programmer* by Andy Hunt & Dave Thomas | Merge sort image is from *Designing and Building Parallel Programs* © Ian Foster.