Tutorial 6.1

External variables

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Local and Global variables

- Local varibles are always allocated in the stack frame for a function
- Global varibles are allocated outside all functions’ stack frame
    - stored in a separate section of RAM

```
int val1                    // global variables

main()
{
     int val2;              // local variables
     ...
}
```

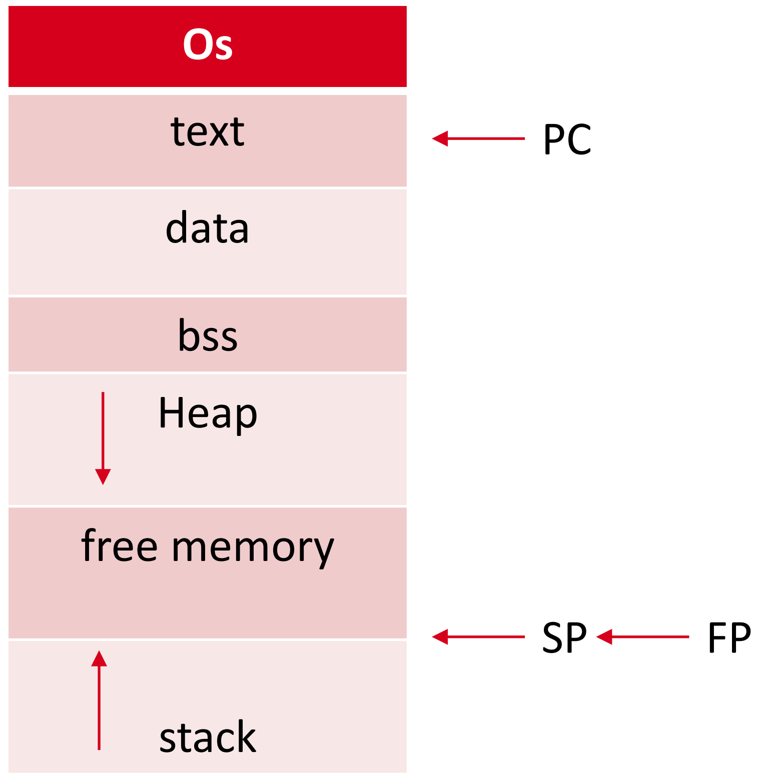
External Varibles

- non-local variables

	Local Variables		External Variables	
Memory Allocation	decrement SP (middle of subroutine)	STP (start of subroutine)	.data/.bss (without .global)	.data/.bss (with .global)
Scope	code block	subroutine	file	program
Lifetime	code block	subroutine	program	program

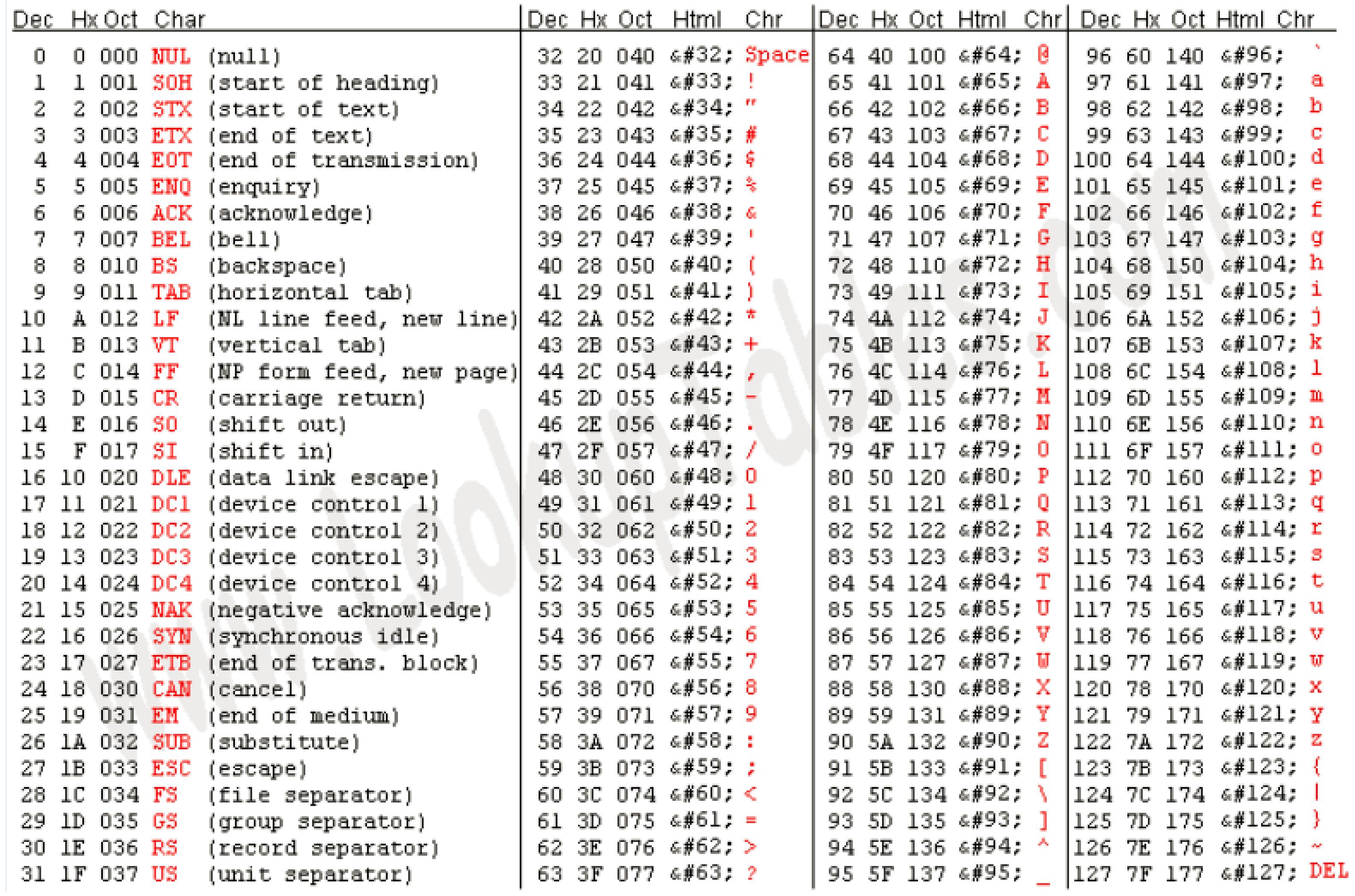
.text, .data, .bss sections

- .text (default section when assembling)
  - program text
  - Read only
  - attempts to write memory causes a segmentation fault
- .data
  - contains programmer-initialized data
  - read/write
- .bss (block starting symbol)
  - contains zero-initialized data
  - read/write



The ASCII Character Set

- American Standard Code for Information Interchange



Dec	Hx	Oct	Char	Dec	Hx	Oct	Html	Chr	Dec	Hx	Oct	Html	Chr	Dec	Hx	Oct	Html	Chr
0	0	000	NUL (null)	32	20	040	&#32;	Space	64	40	100	&#64;	@	96	60	140	&#96;	`
1	1	001	SOH (start of heading)	33	21	041	&#33;	!	65	41	101	&#65;	A	97	61	141	&#97;	a
2	2	002	STX (start of text)	34	22	042	&#34;	"	66	42	102	&#66;	B	98	62	142	&#98;	b
3	3	003	ETX (end of text)	35	23	043	&#35;	#	67	43	103	&#67;	C	99	63	143	&#99;	c
4	4	004	EOT (end of transmission)	36	24	044	&#36;	$	68	44	104	&#68;	D	100	64	144	&#100;	d
5	5	005	ENQ (enquiry)	37	25	045	&#37;	%	69	45	105	&#69;	E	101	65	145	&#101;	e
6	6	006	ACK (acknowledge)	38	26	046	&#38;	&	70	46	106	&#70;	F	102	66	146	&#102;	f
7	7	007	BEL (bell)	39	27	047	&#39;	'	71	47	107	&#71;	G	103	67	147	&#103;	g
8	8	010	BS (backspace)	40	28	050	&#40;	(	72	48	110	&#72;	H	104	68	150	&#104;	h
9	9	011	TAB (horizontal tab)	41	29	051	&#41;	)	73	49	111	&#73;	I	105	69	151	&#105;	i
10	A	012	LF (NL line feed, new line)	42	2A	052	&#42;	*	74	4A	112	&#74;	J	106	6A	152	&#106;	j
11	B	013	VT (vertical tab)	43	2B	053	&#43;	+	75	4B	113	&#75;	K	107	6B	153	&#107;	k
12	C	014	FF (NP form feed, new page)	44	2C	054	&#44;	,	76	4C	114	&#76;	L	108	6C	154	&#108;	l
13	D	015	CR (carriage return)	45	2D	055	&#45;	-	77	4D	115	&#77;	M	109	6D	155	&#109;	m
14	E	016	SO (shift out)	46	2E	056	&#46;	.	78	4E	116	&#78;	N	110	6E	156	&#110;	n
15	F	017	SI (shift in)	47	2F	057	&#47;	/	79	4F	117	&#79;	O	111	6F	157	&#111;	o
16	10	020	DLE (data link escape)	48	30	060	&#48;	0	80	50	120	&#80;	P	112	70	160	&#112;	p
17	11	021	DC1 (device control 1)	49	31	061	&#49;	1	81	51	121	&#81;	Q	113	71	161	&#113;	q
18	12	022	DC2 (device control 2)	50	32	062	&#50;	2	82	52	122	&#82;	R	114	72	162	&#114;	r
19	13	023	DC3 (device control 3)	51	33	063	&#51;	3	83	53	123	&#83;	S	115	73	163	&#115;	s
20	14	024	DC4 (device control 4)	52	34	064	&#52;	4	84	54	124	&#84;	T	116	74	164	&#116;	t
21	15	025	NAK (negative acknowledge)	53	35	065	5	5	85	55	125	&#85;	U	117	75	165	&#117;	u
22	16	026	SYN (synchronous idle)	54	36	066	&#54;	6	86	56	126	&#86;	V	118	76	166	&#118;	v
23	17	027	ETB (end of trans. block)	55	37	067	&#55;	7	87	57	127	&#87;	W	119	77	167	&#119;	w
24	18	030	CAN (cancel)	56	38	070	&#56;	8	88	58	130	&#88;	X	120	78	170	&#120;	x
25	19	031	EM (end of medium)	57	39	071	&#57;	9	89	59	131	&#89;	Y	121	79	171	&#121;	y
26	1A	032	SUB (substitute)	58	3A	072	&#58;	:	90	5A	132	&#90;	Z	122	7A	172	&#122;	z
27	1B	033	ESC (escape)	59	3B	073	&#59;	;	91	5B	133	&#91;	[	123	7B	173	&#123;	{
28	1C	034	FS (file separator)	60	3C	074	&#60;	<	92	5C	134	&#92;	\	124	7C	174	&#124;	|
29	1D	035	GS (group separator)	61	3D	075	&#61;	=	93	5D	135	&#93;	]	125	7D	175	&#125;	}
30	1E	036	RS (record separator)	62	3E	076	&#62;	>	94	5E	136	&#94;	^	126	7E	176	&#126;	~
31	1F	037	US (unit separator)	63	3F	077	&#63;	?	95	5F	137	&#95;	_	127	7F	177	&#127;	DEL

Allocation and initialization

```
// data section: read/write, programmer-initialized data
                .data
a_m:            .byte     10          // 1 byte, a single character(ASCII code:10 -> '\n')
b_m:            .hword    20          // half word: 2 bytes
c_m:            .word     30          // word: 4 bytes
d_m:            .dword    40          // double word: 8 bytes
arraya_m:       .skip     5*4         // 5*4 = 20 bytes of uninitialized memory
arrayb_m:       .word     10, 20, 30, 40, 50                  // array of 5 words
arrayc_m:       .dword    10, 20, 30, 40, 50                  // array of 5 dwords
sa_m:           .string   "this string is null-terminated"    //string with terminator
sb_m:           .asciz    "this string is null terminated too" // string with terminator
sc_m:           .ascii    "this string is not null-terminated"  // string without terminator
char_m:         .byte     'a'
chars_m:        .byte     'h', 'e', 'l', 'l', 'o'
// bss section: read/write, zero-initialized data
                .bss
array_m:        .skip   10*4           // int array
e_m:            .skip   1              // char
f_m:            .skip   2              // short int
// text section: read-only, programmer-initialized data
                .text
const_m:        .word 3                //constant 3
                .balign 4              //word aligned
```

Access memory

```
                    .global main
main:               stp       x29, x30, [sp, -16]!
                    mov       x29, sp
                    // access c_m: int 30
                    adrp      x19, c_m
                    add       x19, x19, :lo12:c_m
                    ldr       w20, [x19]
                    // access a_m: char 10 -> '\n' newline
                    adrp      x19, a_m
                    add       x19, x19, :lo12:a_m
                    ldrb      w21, [x19]
                    // access arrayb using const_m as index
                    adrp      x19, const_m
                    add       x19, x19, :lo12:const_m
                    ldr       w22, [x19]
                    adrp      x19, arrayb_m
                    add       x19, x19, :lo12:arrayb_m
                    ldr       w23, [x19, w22, SXTW 2]

                    // access chars_m and print it one by one
                    //for(int i=0; i<5, i++){               <-- write your code here
                    //        putchar(chars_m[i]);
                    //        }

                    // access sa and print it
                    adrp      x19, sa_m
                    add       x19, x19, :lo12:sa_m
                    mov       x0,  x19
                    bl printf

                    ldp       x29, x30, [sp], 16
                    ret
```

code practice

Solution for accessing chars_m

```
            adrp        x19, chars_m
            add         x19, x19, :lo12:chars_m
            mov         w25, 0
            b test
loop:       ldrb        w0, [x19, w25, SXTW] // char is one byte so shift is
                                            //not needed here
            bl          putchar             // putchar to print a single char

            add         w25, w25, 1
test:       cmp         w25, 5
            b.lt    loop
```

Use gdb to examine external variables in memory

- x/[length][format] &[label_name]
- Eg: x/5d &array_m

reference

- http://edwinckc.com/cpsc355/73-tutorial-7-nov-14-external-variables
- lecture slides