18 System Programming Projects

Reading a Binary File in C on a Windows System

```
FILE *infile, *outfile;
infile = fopen("x.in", "r");
outfile = fopen("x.out", "w");
```

```
infile = fopen("x.in", "rb");   // "b" qualifier needed on Windows
outfile = fopen("x.out", "wb");
```

Reading and Writing Binary Files

```
char buf[100];
int count;
```

```
count = fread(buf, 1, sizeof(buf), infile);
```

Address of input area

Max number of units to read

```
count = fread(&x, sizeof(int), 1, infile);
```

Reading char

```
c = fgetc(infile);


if (c == EOF)
{
   ...
}


signed char c;        // sign extended
unsigned char c;      // zero extended
char c;               // extension is compiler dependent
```

Write to a Binary File

```
count = fwrite(buf, sizeof(buf), 1, outfile);

fputc(c, outfile);
```

Input and Output Functions in C for Text Files

```
count = fscanf(infile, "%d", &x);
fprintf(outfile, "x = %d\n", x);
```

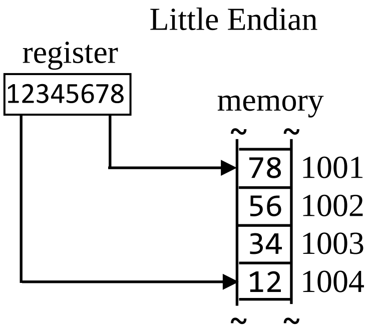
```
fgets(buf, sizeof(buf), infile);
```

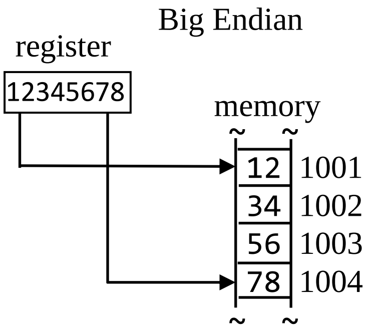
```
while(fgets(buf, sizeof(buf), infile))
{
      ⋮
}
```

```
fputs(buf, outfile);
```

```
fputs("hello\n", outfile);
```

Little Endian and Big Endian


Little Endian


Big Endian

Using Masks and Bitwise Operators

```
y = x & 0x1ff;
```

```
00...01010001 000010010 x
00...00000000 111111111 mask
00...00000000 000010010 result
```

```
if (x & 0x20)
{
   execute if sixth bit from right is 1
}
```

```
00...0100000
```

```
y = x | 0x20;
```

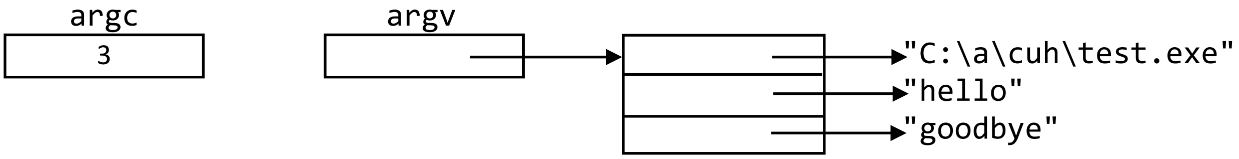
```
00...010100010 00010010 x
00...000000000 00100000 mask
00...010100010 00110010 result
```

Accessing Command Line Arguments

```
test hello goodbye
```

```
#include <stdio.h>
int main(int argc, char *argv[])
{
   int i;
   for (i = 0, i < argc; i++)
      printf("%s\n", argv[i]);
   return 0;
}
```

```
test hello goodbye
```



```
C:\a\cuh\test.exe
hello
goodbye
```

```
test hello goodbye > test.out
```

test.out

```
C:\a\cuh\test.exe
hello
goodbye
```

Common Bugs in C Programs

```
int *p;      // bad
*p = 7;

int x, *p;   // good
p = &x;                           // assign p the address of x
*p = 7;                           // ok to dereference p
p = (int *)malloc(sizeof(int));  // assign p addr of allocated storage
*p = 7;                           // ok to dereference p


char a[100];  // ugly
a = "hello";

strcpy(a, "hello");


char *p = "hello";
char *q = "bye";
strcat(p, q);   // do not do this!

char buf[100];
strcpy(buf, p);       // copy "hello" into buf
strcat(buf, q);       // concatenate "bye" to "hello" in buf
p = buf;              // assign p the address of concatenated string
printf("%s\n", buf);  // displays hellobye
printf("%s\n", p);    // displays hellobye


printf("x = ", x);      // wrong: needs one conversion code in 1st arg
printf("x = %d\n", x);  // right: one conversion code in 1st arg
```

Field Width in printf Conversion Codes

```
   printf("---%d---\n", 123);
```

displays

```
---123---
```

```
   printf("---%8d---\n", 123);
```

8 is the field width

displays

```
---     123---
```

```
   printf("---%4d---\n", 12345678);
```

displays

```
---12345678---
```

```
   printf("---%08d---\n", 123);
```

displays

```
---00000123---
```

Displaying a Byte in Hex

```
unsigned char uc;
signed char sc;
char c;
```

- `i` and `j` have the type `int` and are 32-bits wide
- the eight-bit value in both `uc` and `sc` is F1 hex (11110001 in binary)

```
i = uc;    // i is assigned 241 (000000F1 hex)
j = sc;    // j is assigned -15 (FFFFFFF1 hex)
```

Rule: The type of extension—zero or signed—*depends on the type of the variable* extended.

```
printf("%02X", uc);         // displays F1
printf("%02X", sc);         // displays FFFFFFF1
printf("%02X", sc & 0xff);  // displays F1

printf("%02X", sc);          // displays FFFFFFF1   Why???


printf("%c", sc);            // displays what???
```

The calling sequence extends the value in `sc` to 32 bits before passing it to `printf`.

Because of the conversion code is `%c`, `printf` accesses and displays the character *in only the low-order byte* of the 32-bit value it is passed.

Hex/ASCII Display Project

```
h1 h1test.txt
```

displays

```
YOUR NAME HERE   h1 h1test.txt   Thu Jun 03 16:50:08 2021

    0:  5468 6973 2070 726F 6772 616D 2061 6C6C
   10:  6F77 7320 796F 7520 746F 206C 6F6F 6B20
   20:  696E 7369 6465 2061 2066 696C 6520 746F
   30:  2073 6565 2077 6861 7420 6973 200D 0A72
   40:  6561 6C6C 7920 7468 6572 652E 2042 7574
   50:  2074 6F20 6265 2075 7365 6675 6C2C 2079
   60:  6F75 206E 6565 6420 746F 206B 6E6F 7720
   70:  6865 7861 6465 6369 6D61 6C20 0D0A 6E6F
   80:  7461 7469 6F6E 2E20 5265 6D65 6D62 6572
   90:  2061 203D 2031 302C 2062 203D 2031 312C
   A0:  2063 203D 2031 322C 2064 203D 2031 332C
   B0:  2065 203D 2031 342C 200D 0A61 6E64 2066
   C0:  203D 2031 352E 0D0A 0001 FFF3 4279 65
```

```
// h1shell.c
Your name here as a comment
#include <stdio.h>    // for I/O
#include <stdlib.h>   // for exit()
#include <time.h>     // for time functions

int main(int argc, char *argv[])
{
   FILE *infile;
   int i, numread;
   unsigned char buf[32768];
   time_t timer;


   if (argc != 2)
   {
        printf("Wrong number of command line arguments\n");
        printf("Usage: h1 <inputfilename>\n");
        exit(1);
   }

   // display your name, command line args, and time
   time(&timer);                Replace with your name
   printf("YOUR NAME HERE   %s %s   %s",
               argv[0], argv[1], asctime(localtime(&timer)));

   infile = fopen(argv[1], "rb");
   if (!infile)
   {
      printf("Cannot open input file %s\n", argv[1]);
      exit(1);
   }
   numread = fread(buf, 1, sizeof(buf), infile);

   for (i = 0; i < numread; i++)
   {
      Code missing here:
      Display buf[i] so that 16 bytes appear on each line,
      with a space between each pair of bytes as shown in the textbook.
      Use i to determine when to insert space and newline. Start each
      line with the hex address of the start of that line followed by a colon.
   }
}
```

No Limit on File Size for h2

```
// h2shell.c
Your name here as a comment
#include <stdio.h>    // for I/O
#include <stdlib.h>   // for exit()
#include <time.h>     // for time functions

FILE *infile;

// nextbyte() handles any input file size
int nextbyte()
{
   Declaring the following variables static so they retain their values between calls.
   static unsigned char buf[100];
   static int numread, bufindex = sizeof(buf);

   if (bufindex == sizeof(buf))
   {
      Code missing here:
      Read next 100-byte block and reset bufindex to 0.
      Assign to numread the number of bytes actually read.
   }

   if (bufindex < numread)
   {
      Code missing here:
      Return byte in buf[bufindex] as an int.
      Increment bufindex.
   }
   else
      return -1;  // -1 signals end of file
}

int main(int argc, char *argv[])
{
   int i, byte;
   time_t timer;

   if (argc != 2)
   {
        printf("Wrong number of command line arguments\n");
        printf("Usage: h2 <inputfilename>\n");
        exit(1);
   }
   // display your name, command line args, and time
   time(&timer);               Replace with your name
   printf("YOUR NAME HERE   %s %s   %s",
           argv[0], argv[1], asctime(localtime(&timer)));

   infile = fopen(argv[1], "rb");
   if (!infile)
   {
      printf("Cannot open input file %s\n", argv[1]);
      exit(1);
   }

   i = 0;  // use i to determine when to insert space and newline
   while (1)
   {
      byte = nextbyte();
      if (byte == -1)
         break;
      Code missing here:
      Display byte here so that 16 bytes appear on each line,
      with a space between each pair of bytes as shown in the textbook.
      Use i to determine when to insert space and newline. Start each
      line with the hex address of the start of that line followed by a colon.
      i++;
   }
}
```

h3 Displays Characters Corresponding to ASCII Codes

```
     h3 h3test.txt > h3test.out
```

```
YOUR NAME HERE   h3 h3test.txt   Thu Jun 03 16:50:08 2021

    0:  5468 6973 2070 726F 6772 616D 2061 6C6C   This program all
   10:  6F77 7320 796F 7520 746F 206C 6F6F 6B20   ows you to look 
   20:  696E 7369 6465 2061 2066 696C 6520 746F   inside a file to
   30:  2073 6565 2077 6861 7420 6973 200D 0A72    see what is ..r
   40:  6561 6C6C 7920 7468 6572 652E 2042 7574   eally there. But
   50:  2074 6F20 6265 2075 7365 6675 6C2C 2079    to be useful, y
   60:  6F75 206E 6565 6420 746F 206B 6E6F 7720   ou need to know 
   70:  6865 7861 6465 6369 6D61 6C20 0D0A 6E6F   hexadecimal ..no
   80:  7461 7469 6F6E 2E20 5265 6D65 6D62 6572   tation. Remember
   90:  2061 203D 2031 302C 2062 203D 2031 312C    a = 10, b = 11,
   A0:  2063 203D 2031 322C 2064 203D 2031 332C    c = 12, d = 13,
   B0:  2065 203D 2031 342C 200D 0A61 6E64 2066    e = 14, ..and f
   C0:  203D 2031 352E 0D0A 0001 FFF3 4279 65       = 15.......Bye
```

Machine Interpreter Level 1 Project

```
// i1shell.c
Your name here as a comment
#include <stdio.h>  // for I/O functions
#include <stdlib.h> // for exit()
FILE *infile;
short r[8], mem[65536], offset6, imm5, imm9, pcoffset9, pcoffset11,
      regsave1, regsave2;
unsigned short ir, pc, opcode, code, dr, sr, sr1, sr2, bit5, bit11,
               trapvect8, n, z, c, v;
char letter;
time_t timer;

void setnz(short r)
{
   n = z = 0;
   if (r < 0)    // is result negative?
      n = 1;     // set n flag
   else
   if (r == 0)   // is result zero?
      z = 1;     // set z flag
}

void setcv(short sum, short x, short y)
{
   v = c = 0;
   if (x >= 0 && y >= 0)    // if both non-negative, then no carry
      c = 0;
   else
   if (x < 0 && y < 0)      // if both negative, then carry
      c = 1;
   else
   if (sum >= 0)            // if signs differ and sum non-neg, then carry
      c = 1;
   else                    // if signs differ and sum neg, then no carry
      c = 0;
   // if signs differ then no overflow
   if ((x < 0 && y >= 0) || (x >= 0 && y < 0))
      v = 0;
   else
   // if signs the same and sum has different sign, then overflow
   if ((sum < 0 && x >= 0) || (sum >= 0 && x < 0))
      v = 1;
   else
      v = 0;
}
```

```
int main(int argc, char *argv[])
{
   {
       printf("Wrong number of command line arguments\n");
       printf("Usage: i1 <inputfilename>\n");
       exit(1);
   }

   // display your name, command line args, time
   time(&timer);      // get time
   printf("YOUR NAME HERE     %s %s     %s",
           argv[0], argv[1], asctime(localtime(&timer)));

   infile = fopen(argv[1], "rb");      // open file in binary mode
   if (!infile)
   {
      printf("Cannot open input file %s\n", argv[1]);
      exit(1);
   }

   fread(&letter, 1, 1, infile);       // test for and discard file sig
   if (letter != 'o')
   {
      printf("%s not an lcc file\n", argv[1]);
      exit(1);
   }
   fread(&letter, 1, 1, infile);       // test for and discard 'C'
   if (letter != 'C')
   {
      printf(("Missing C header entry in %s\n", argv[1]);
      exit(1);
   }

   fread(mem, 1, sizeof(mem), infile); // read machine code into mem

   while (1)
   {
      // fetch instruction, load it into ir, and increment pc
      ir = mem[pc++];

      // isolate the fields of the instruction in the ir
      opcode = ir >> 12;                    // get opcode
      pcoffset9 = ir << 7;                  // left justify pcoffset9 field
      pcoffset9 = imm9 = pcoffset9 >> 7;    // sign extend and rt justify
      pcoffset11 = ...                      // left justify pcoffset11 field
      pcoffset11 = ...                      // sign extend and rt justify
      imm5 = ...                            // left justify imm5 field
      imm5 = ...                            // sign extend and rt justify
      offset6 = ...                         // left justify offset6 field
```

```
offset6 = ...                         // sign extend and rt justify
trapvect8 = ir & 0xff;                // get trapvect8 field
code = dr = sr = ...                  // get code/dr/sr, rt justify
sr1 = baser = (ir & 0x01c0) >> 6;     // get second reg, rt justify
sr2 = ...                             // get third reg
bit5 = ...                            // get bit 5
bit11 = ir & 0x0800;                  // get bit 11

// determine and execute instruction just fetched
switch (opcode)
{
   case 0:                            // branch instructions
      switch(code)
      {
         case 0: if (z == 1)              // brz
                    pc = pc + pcoffset9;
                 break;
         case 1: if (z == 0)              // brnz
                    pc = pc + pcoffset9;
                 break;

         code missing here

         case 7: pc = pc + pcoffset9;    // br
                 break;
      }
      break;
   case 1:                               // add
      if (bit5)
      {
         regsave1 = r[sr1];
         r[dr] = regsave1 + imm5;
         // set c, v flags
         setcv(r[dr], regsave1, imm5);
      }
      else
      {
         regsave1 = r[sr1]; regsave2 = r[sr2];
         r[dr] = regsave1 + regsave2;
         // set c, v flags
         setcv(r[dr], regsave1, regsave2);
      }
      // set n, z flags
      setnz(r[dr]);
      break;
   case 2:                            // ld

   code missing here
```

```
         case 9:                           // not
            // ~ is the not operator in C
            r[dr] = ~r[sr1];
            // set n, z flags
            setnz(r[dr]);
            break;

         code missing here

         case 12:                          // jmp/ret
            pc = r[baser];
            break;

         code missing here

         case 14:                          // lea
            r[dr] = pc + pcoffset9;
            break;
         case 15:                          // trap
            if (trapvect8 == 0x00)         // halt
               exit(0);
            else
            if (trapvect8 == 0x01)         // nl
               code missing here
            else
            if (trapvect8 = 0x02)          // dout
               code missing here
            break;
      }
}
```

Assembler Level 1 Project

```
// a1shell.c
Your name here as a comment
#include <stdio.h>   // for I/O functions
#include <stdlib.h>  // for exit()
#include <string.h>  // for string functions
#include <ctype.h>   // for isspace(), tolower()
#include <time.h>    // for time functions

FILE *infile, *outfile;
short pcoffset9, pcoffset11, imm5, imm9, offset6;
unsigned short symadd[500], macword, dr, sr, sr1, sr2, baser, trapvect8;
char outfilename[100], linesave[100], buf[100], *symbol[500], *p1, *p2,
     *mnemonic, *o1, *o2, *o3, *label;
int stsize, num, linenum, rc, loc_ctr;
time_t timer;

// case insensitive string compare
short int strcmpi(const char *p, const char *q)
{
   // Returns 0 if two strings are equal.
   char a, b;
   while (1)
   {
      a = tolower(*p); b = tolower(*q);
      if (a != b) return a-b;
      if (a == '\0') return 0;
      p++; q++;
   }
}

void error(char *p)
{
   Code missing here:
   Displays error message p points to, line number in linenum, and line in linesave.
}

int isreg(char *p)
{
   Code missing here:
   Returns 1 if p points to a register name.  Otherwise, returns 0.
}

unsigned short getreg(char *p)
{
   Code missing here:
   Returns register number of the register whose name p points to.
   If p does not point to a register name, call error().
}

unsigned short getadd(char *p)
{
   Code missing here:
   Returns address of symbol that p points by accessing the symbol table.
   Calls error() if symbol not in symbol table.
}

int main(int argc,char *argv[])
{
   if (argc != 2)
   {
      printf("Wrong number of command line arguments\n");
      printf("Usage: a1 <inputfilename>\n");
      exit(1);
   }
   // display your name, command line args, and time
   time(&timer);           Replace with your name
   printf("YOUR NAME HERE   %s %s   %s",
           argv[0], argv[1], asctime(localtime(&timer)));

   infile = fopen(argv[1], "r");
   if (!infile)
   {
      printf("Cannot open input file %s\n", argv[1]);
      exit(1);
   }

   // construct output file name
   strcpy(outfilename, argv[1]);        // copy input file name
   p1 = strrchr(outfilename, '.');      // search for period in extension
   if (p1)                              // name has period
   {
#ifdef _WIN32                           // defined only on Windows systems
      p2 = strrchr(outfilename, '\\' ); // compiled if _WIN32 is defined
#else
      p2 = strrchr(outfilename, '/');   // compiled if _WIN32 not defined
#endif
      if (!p2 || p2 < p1)               // input file name has extension?
         *p1 = '\0';                    // null out extension
   }
   strcat(outfilename, ".e");           // append ".e" extension

   outfile = fopen(outfilename, "wb");
   if (!outfile)
   {
      printf("Cannot open output file %s\n", outfilename);
      exit(1);
   }

   loc_ctr = linenum = 0;           // initialize
   fwrite("oC", 2, 1, outfile);     // output empty header
   // Pass 1
   printf("Starting Pass 1\n");
   while (fgets(buf, sizeof(buf), infile))
   {
      linenum++;                    // update line number
      p = buf;
      while (isspace(*p)) p++;
      if (*p == '\0' || *p ==';')  // if line all blank, go to next line
         continue;
      strcpy(linesave, buf);       // save line for error messages
      if (!isspace(buf[0]))        // line starts with label
      {
         label = strdup(strtok(buf, " \r\n\t:"));
         Add code here that checks for a duplicate label, use strcmp().
         symbol[stsize] = label;
         symadd[stsize++] = loc_ctr;
         mnemonic = strtok(NULL," \r\n\t"); // get ptr to mnemonic/directive
         o1 = strtok(NULL, " \r\n\t");      // get ptr to first operand
      }
      else   // tokenize line with no label
      {
         mnemonic = strtok(buf, " \r\n\t"); // get ptr to mnemonic
         o1 = strtok(NULL, " \r\n\t");     // get ptr to first operand
      }
      if (mnemonic = NULL)           // check for mnemonic or directive
         continue;
      if (!strcmp(mnemonic, ".blkw"))
      {
         if (o1)
            rc = sscanf(o1, "%d", &num);    // get size of block from o1
         else
            error("Missing operand");
         if (rc != 1 || num > (65536 – loc_ctr) || num < 1)
            error("Invalid operand");
         loc_ctr = loc_ctr + num;
      }
      else
         loc_ctr++;
      if (loc_ctr > 65536)
         error("Program too big");
   }

   rewind(infile);
```

```
// Pass 2
printf("Starting Pass 2\n");
loc_ctr = linenum = 0;
while (fgets(buf, sizeof(buf), infile))
{
   linenum++;
   Code missing here:
   Discard blank/comment lines.
   Save buf in linesave as in pass 1.
   Tokenize entire current line.
   Do not make any new entries into the symbol table.

   if (mnemonic == NULL)
      continue;
   if (!strncmp(mnemonic, "br", 2)
   {
      if (!mstrcmpi(mnemonic, "br" ))
         macword = 0x0e00;
      else
      if (!mstrcmpi(mnemonic, "brz" ))
         macword = 0x0000;
      else
      if (!mstrcmpi(mnemonic, "brnz" ))
         macword = 0x0200;
      else
      if (!mstrcmpi(mnemonic, "brn" ))
         macword = 0x0400;
      else
      if (!mstrcmpi(mnemonic, "brp" ))
         macword = 0x0600;
      else
      if (!mstrcmpi(mnemonic, "brlt" ))
         macword = 0x0800;
      else
      if (!mstrcmpi(mnemonic, "brgt" ))
         macword = 0x0a00;
      else
      if (!mstrcmpi(mnemonic, "brc" ))
         macword = 0x0c00;
      else
         error("Invalid branch mnemonic");

      pcoffset9 = (getadd(o1) - loc_ctr - 1);   // compute pcoffset9
      if (pcoffset9 > 255 || pcoffset9 < -256)
         error("pcoffset9 out of range");
      macword = macword | (pcoffset9 & 0x01ff); // assemble inst
      fwrite(&macword, 2, 1, outfile);   // write out instruction
      loc_ctr++;
   }
```

```
else
if (!strcmp(mnemonic, "add" ))
{
   if (!o3)
      error("Missing operand");
   dr = getreg(o1) << 9;   // get and position destination reg number
   sr1 = getreg(o2) << 6;  // get and position source reg 1 number
   if (isreg(o3)) // 3rd operand a register?
   {
      sr2 = getreg(o3);// get third reg number
      macword = 0x1000 | dr | sr1 | sr2; // assemble inst
   }
   else
   {
      if (sscanf(o3,"%d", &num) != 1) // convert imm5 field
         error("Bad imm5");
      if (num > 15 || num < -16)
         error("imm5 out of range");
      macword = 0x1000 | dr | sr1 | 0x0020 | (num & 0x1f);
   }
   fwrite(&macword, 2, 1, outfile); // write out instruction
   loc_ctr++;
}
else
if (!strcmp(mnemonic, "ld" ))
{
   dr = getreg(o1) << 9;   // get and position destination reg number
   pcoffset9 = (getadd(o2) – loc_ctr - 1);
   if (pcoffset9 > 255 || pcoffset9 < -256)
      error("pcoffset9 out of range");
   macword = 0x2000 | dr | (pcoffset9 & 0x1ff);   // assemble inst
   fwrite(&macword, 2, 1, outfile); // write out instruction
   loc_ctr++;
}
```

code missing here

```
else
if (!strcmp(mnemonic, "jmp" ))
{
   baser = getreg(o1) << 6;         // get and position reg number
   macword = 0xc000 | baser;        // assemble instruction
   fwrite(&macword, 2, 1, outfile); // write out instruction
   loc_ctr++;
}
```

code missing here

```
      else
      if (!strcmp(mnemonic, ".zero"))
      {
         macword = 0;
         sscanf(o1, "%d", &num);            // get size of block
         loc_ctr = loc_ctr + num;           // adjust loc_ctr
         while (num--)                      // write out a block of zeros
            fwrite(&macword, 2, 1, outfile);
      }
      else
         error("Invalid mnemonic or directive");
   }
   Close files.
}
```

Machine Interpreter Level 2 Project

Extend your i1 interpreter so that it supports, A, S, and C header entries and a command-line-specified load point.

```
i2 i2test.e 500
```

To read S and A addresses:

```
fread(&start, 2, 1, infile);  // to read addresses in S and A entries
```

where start is declared as an unsigned short integer.

Assembler Level 2 Project

```
     fwrite("S", 1, 1, outfile);    // output S entry
     fwrite(&addr, 2, 1, outfile);
```

```
; a2test.a
          .start s
          halt
s:        lea r0, c7
          st r0, ac7
          ld r0, x
          dout           ; 1
          nl
          add r0, r0, r0
          dout           ; 2
          nl
          add r0, r0, 1
          dout           ; 3
          nl
          add r0, r0, 3
          and r0, r0, 4
          dout           ; 4
          nl
          br L1
          halt
L1:
          brp L2
          halt
L2:
ABC:
          add r1, r0, 0
          not r1, r1
          brn L3
          halt
L3:       br L4
X:        .word 1
L4:       and r2, r2, 0
          brz L5
          halt
          .blkw 3
L5:       lea r3, L6
          jmp r3
          halt
L6:       bl r1sub       ; 5
          lea r4, r2sub
          blr r4         ; 6
          ld r0, ac7
          ldr r0, r0, 0
          dout          ; 7
          nl
          lea r4, c6
          ldr r0, r4, 4
          dout          ; 8
          nl
          ld  r5, minus
          not r0, r5
          dout          ; -9
          nl
          add r0, r0, -1
          st r0, save
          ld r0, save
          dout          ; -10
          nl
          add r0, r0, -1
          ld r1, ac7
          str r0, r1, 0
          ld  r0, c7
          dout          ; -11
          nl
          add r0, r0, -1
          lea r1, save
          str r0, r1, 1
          ld  r0, save2
          dout          ; -12
          nl
          halt
          ; hello

r1sub:    ld r0, c5
          dout           ; 5
          nl
          ret
c5:       .word 5
minus:    .word 8
r2sub:    ld r0, c6
          dout
          nl
          ret
c6:       .word 6
c7:       .word 7
ac6:      .word c6
ac7:      .word c7
c8:       .word 8
save:     .word -5
save2:    .word 100
```

Module Picture Project

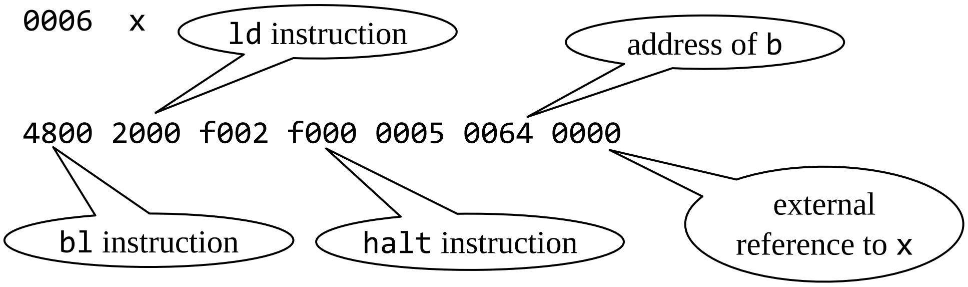
```
     ; ptest.a
     .global a
     .global b
     .extern sub
     .extern x
     .start s
S:   bl sub
     ld  r0,x
     dout
     halt
a:   .word b
b:   .word 100
c:   .word x
```

```
p ptest.o
```

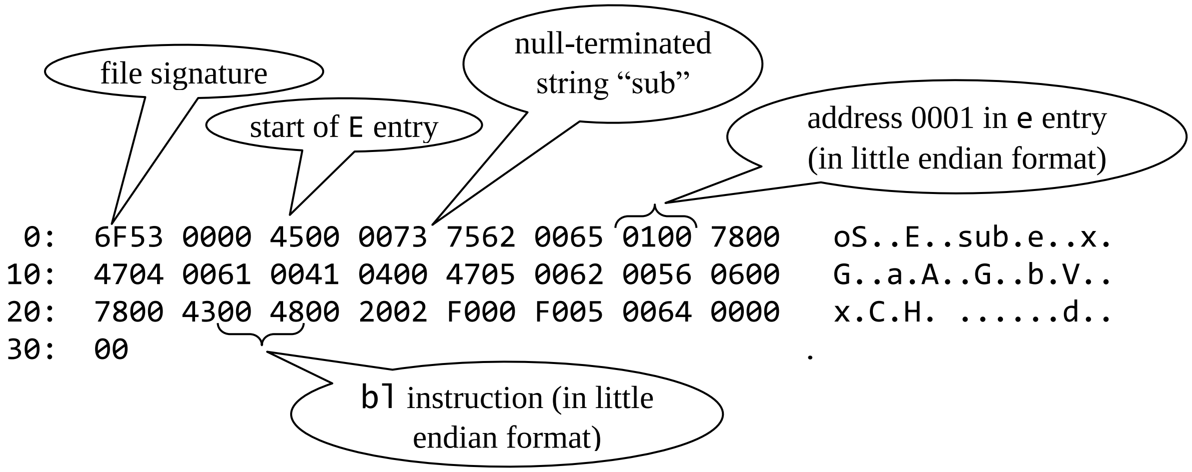
displays

```
YOUR NAME HERE   p ptest.o   Thu Jun 03 16:50:08 2021

Header:
    o
    S  0000
    E  0000  sub
    e  0001  x
    G  0004  a
    A  0004
    G  0005  b
    V  0006  x
    C
Code:
    0: 4800 2000 f002 f000 0005 0064 0000
```



`h3` display:



```
 0:  6F53 0000 4500 0073 7562 0065 0100 7800   oS..E..sub.e..x.
10:  4704 0061 0041 0400 4705 0062 0056 0600   G..a.A..G..b.V..
20:  7800 4300 4800 2002 F000 F005 0064 0000   x.C.H. ......d..
30:  00                                        .
```

file signature
start of E entry
null-terminated string “sub”
address 0001 in e entry (in little endian format)
bl instruction (in little endian format)

```
// pshell.c
Your name here as a comment.
#include <stdio.h>   // for I/O functions
#include <stdlib.h>  // for exit()
#include <time.h>    // for time functions
int main(int argc,char *argv[])
{
   FILE *infile;
   unsigned short addr, codeword;
   char c;
   int i;
   time_t timer;

   if (argc != 2)
   {
      printf("Wrong number of command line arguments\n");
      printf("Usage: p <inputfilename>\n");
      exit(1);
   }

   infile = fopen(argv[1], “r”);
   if (!infile)
   {
      printf("Cannot open input file %s\n", argv[1]);
      exit(1);
   }

   // display your name, command line args, and time
   time(&timer);               Replace with your name
   printf("YOUR NAME HERE   %s %s   %s",
           argv[0], argv[1], asctime(localtime(&timer)));

   // process header entries
   printf("\nHeader:\n");
   c = fgetc(infile);
   if (c == 'o')
      printf("    o\n");
   else
   {
      printf("%s not an lcc file\n", argv[1]);
      exit(1);
   }
   while (1)
   {
      c = fgetc(infile);
      if (c == 'C')
      {
         printf("    C\n");
         break;
      }
      if (c == 'S')
      {
         if (fread(&addr, 2, 1, infile) != 1)
         {
            printf("Invalid S entry\n");
            exit(1);
         }
         printf("    S  %04hx\n", addr);    // %hx conversion code for short
      }
      else
      if (c == 'G')
      {
         if (fread(&addr, 2, 1, infile) != 1)
         {
            printf("Invalid G entry\n");
            exit(1);
         }
         printf("    G  %04hx ", addr);
         while (1)  // read and display string in G entry char by char
         {
            c = fgetc(infile);
            if (c == '\0')
               break;
            printf("%c", c);  // displays characters as read in
         }
         printf("\n");
      }
      else
      if (c == 'E')
      {
         code missing here
      }
      else
      if (c == 'e')
      {
         code missing here
      }
      else
      if (c == 'V')
      {
         code missing here
      }
      else
      if (c == 'A')
      {
         code missing here
      }
      else
```

```
      {
         printf("Invalid header entry in %s\n", argv[1]);
         exit(1);
      }
   }

   // process machine code
   i = 0;
   printf("\nCode:\n");
   while (fread(&codeword, 2, 1, infile))
   {
      Code missing here:
      Display word in codeword, 8 words per line, 1 space separating
      each code word, with each line starting with the hex address of
      the first word on that line as shown in the textbook.
      Use i to determine when to output hex address and newline.
      i++;
   }
}
```

Linker Project

```
// lshell.c
Your name here as a comment
#include <stdio.h>    // for I/O functions
#include <stdlib.h>   // for exit()
#include <time.h>     // for time functions

int i;

unsigned short temp, inst, addr;
char buf[300];

FILE *infile;
FILE *outfile;
char c, *p, letter;

unsigned short mca[65536];
int mcaindex;

unsigned short start;
int gotstart;

unsigned short Gadd[1000];
char *Gptr[1000];
int Gindex;

unsigned short Eadd[1000];
char *Eptr[1000];
int Eindex;

unsigned short eadd[1000];
char * eptr[1000];
int eindex;

unsigned short Aadd[1000];
int Amodadd[1000];
int aindex;

unsigned short Vadd[1000];
char *Vptr[1000];
int Vindex;

time_t timer;

int main(int argc,char *argv[])
{
   if (argc < 2)
```

```
{
     printf("Wrong number of command line arguments\n");
     printf("Usage: l <objmodulename1> <objmodulename2> ... \n");
     exit(1);
}

// display your name, command line args, time
time(&timer);      // get time
printf("YOUR NAME HERE   %s %s  %s",
        argv[0], argv[1], asctime(localtime(&timer)));

//================================================================
// Step 1:
// For each module, store header entries into tables with adjusted
// addresses and store machine code in mca (the machine code array).

for (i = 1; i < argc; i++)
{
   infile = fopen(argv[i], "rb");
   if (!infile)
   {
      printf("Cannot open %s\n", argv[i]);
      exit(1);
   }
   printf("Linking %s\n", argv[i]);
   letter = fgetc(infile);
   if (letter != 'o')
   {
      printf("Not a linkable file\n");
      exit(1);
   }
   while (1)
   {
      letter = fgetc(infile);
      if (letter == 'C')
         break;
      else
      if (letter == 'S')
      {
         if (fread(&addr, 2, 1, infile) != 1) // addr unsigned short
         {
            printf("Invalid S entry\n");
            exit(1);
         }
         if (gotstart)
         {
            printf("More than one entry point\n");
            exit(1);
         }
   gotstart = 1;                   // indicate S entry processed
   start = addr + mcaindex;        // save adjusted address
}
else
if (letter == 'G')
{
   if (fread(&addr, 2, 1, infile) != 1)
   {
      printf("Invalid G entry\n");
      exit(1);
   }
   Gadd[Gindex] = addr + mcaindex; // save adjusted address
   j = 0;
   do                              // get string in G entry
   {
      letter = fgetc(infile);
      buf[j++] = letter;
   } while (letter != '\0');
   j = 0;
   while (j < Gindex)     // check for multiple definitions
   {
      if (!strcmp(buf, Gptr[j]))
      {
         printf("Multiple defs of global var %s\n", buf);
         exit(1);
      }
      else
         j++;
   }
   Gptr[Gindex++] = strdup(buf);   // save string
}
else
if (letter == 'E')
{
   code missing here
}
else
if (letter == 'e')
{
   code missing here
}
else
if (letter == 'V')
{
   code missing here
}
else
if (letter == 'A')
{
```

```
         code missing here
      }
      else
      {
         printf("Invalid header entry in %s\n", argv[i]);
         exit(1);
      }
   }

   // add machine code to machine code array
   while(fread(&inst, 2, 1, infile))
   {
      mca[mcaindex++] = inst;
   }
   fclose(infile);
}

//==================================================================
// Step 2: Adjust external references

// handle E references
for (i = 0; i < Eindex; i++)
{
   for (j = 0; j < Gindex; j++)
      if(!strcmp(Eptr[i], Gptr[j]))
         break;
   if (j >= Gindex)
   {
      printf("%s is an undefined external reference", Eptr[i]);
      exit(1);
   }
   mca[Eadd[i]] = (mca[Eadd[i]] & 0xf800) |
                  ((mca[Eadd[i]] + Gadd[j] - Eadd[i] - 1) & 0x7ff);
}
// handle e entries
for (i = 0; i < eindex; i++)
{
    code missing here
}

// handle V entries
for (i = 0; i < Vindex; i++)
{
    code missing here
}

//==================================================================
// Step 3: Handle A entries
for (i = 0; i < aindex; i++)
```

```
      Code missing here.  Only 1 statement needed to handle each A entry

   //================================================================
   // Step 4: Write out executable file
   outfile = fopen("link.e", "wb");
   if (!outfile)
   {
      printf("Cannot open output file link.e\n");
      exit(1);
   }
   printf("Creating executable file link.e\n");
   // Write out start entry if there is one
   if (gotstart)
   {
      fwrite("S", 1, 1, outfile);
      fwrite(&start, 2, 1, outfile);
   }
   // Write out G entries
   for (i = 0; i < Gindex; i++)
   {
      fwrite("G", 1, 1, outfile);
      fwrite(Gadd + i, 2, 1, outfile);
      fprintf(outfile, "%s", Gptr[i]);
      fwrite("", 1, 1, outfile);
   }
   // Write out V entries as A entries
   for (i = 0; i < Vindex; i++)
   {
       Code missing here:
       Write out V entries as A entries
   }
   // Write out A entries
   for (i = 0; i < Aindex; i++)
   {
       Code missing here:
       Write out A entries
   }
   // Terminate header
   fwrite("C", 1, 1, outfile);

   // Write out code
   for (i = 0; i < mcaindex; i++)
   {
      fwrite(mca + i, 2, 1, outfile);
   }
   fclose(outfile);
}
```