

EECS 22: Advanced C Programming

Lecture 14

Rainer Dömer

doemer@uci.edu

The Henry Samueli School of Engineering
Electrical Engineering and Computer Science
University of California, Irvine

Lecture 14: Overview

- Dynamic Data Structures
 - Linked List
 - Double-linked List
 - Example: Student records
 - `Student.h`
 - `Student.c`
 - `StudentList.h`
 - `StudentList.c`
 - `Makefile`

Dynamic Data Structures

- Arrays
 - Static: size fixed at compile time
 - Dynamic: size fixed at time of allocation
 - Arrays cannot grow or shrink after allocation!
- Linked Lists
 - Dynamic: list length is flexible at run time
 - At program run time, list elements can be...
 - Added (allocated),
 - Removed (deleted), and
 - Moved (re-linked), as needed!
 - Example: Single-linked list
 - Each list element contains a pointer to the next element

```
struct ListItem
{
    struct ListItem *Next;
    defined_type    Data;
};
```

Next

Data

EECS22: Advanced C Programming, Lecture 14 (c) 2013 R. Doemer 3

Dynamic Data Structures

- Double-Linked List (with header)
 - Example: List of Student Records
 - 1. Empty list

Length	0
First	•
Last	•

EECS22: Advanced C Programming, Lecture 14 (c) 2013 R. Doemer 4

Dynamic Data Structures

- Double-Linked List (with header)
 - Example: List of Student Records

The diagram shows a header structure with three fields: Length (value 1), First (points to the first node), and Last (points to the first node). Below the header is a node structure with four fields: List, Next, Prev, and Student. The Student field points to a student record structure with three fields: ID (1002), Name ("John Doe"), and Grade ('C').

1. Empty list
2. Add a student

EECS22: Advanced C Programming, Lecture 14
(c) 2013 R. Doemer
5

Dynamic Data Structures

- Double-Linked List (with header)
 - Example: List of Student Records

The diagram shows a header structure with three fields: Length (value 2), First (points to the first node), and Last (points to the second node). There are two nodes. The first node has Next pointing to the second node and Student pointing to a record with ID 1002, Name "John Doe", and Grade 'C'. The second node has Prev pointing to the first node and Student pointing to a record with ID 1003, Name "Jim Doe", and Grade 'B'.

1. Empty list
2. Add a student
3. Append a student

EECS22: Advanced C Programming, Lecture 14
(c) 2013 R. Doemer
6

Dynamic Data Structures

- Double-Linked List (with header)
 - Example: List of Student Records

The diagram shows a header node with fields Length (3), First, and Last. Three nodes are linked in a double-linked list. Each node has List, Next, Prev, and Student pointers. The first node's Student pointer points to a record with ID 1001, Name 'Jane Doe', and Grade 'A'. The second node's Student pointer points to a record with ID 1002, Name 'John Doe', and Grade 'C'. The third node's Student pointer points to a record with ID 1003, Name 'Jim Doe', and Grade 'B'.

1. Empty list
2. Add a student
3. Append a student
4. Prepend a student

EECS22: Advanced C Programming, Lecture 14
(c) 2013 R. Doemer
7

Dynamic Data Structures

- Double-Linked List (with header)
 - Example: List of Student Records

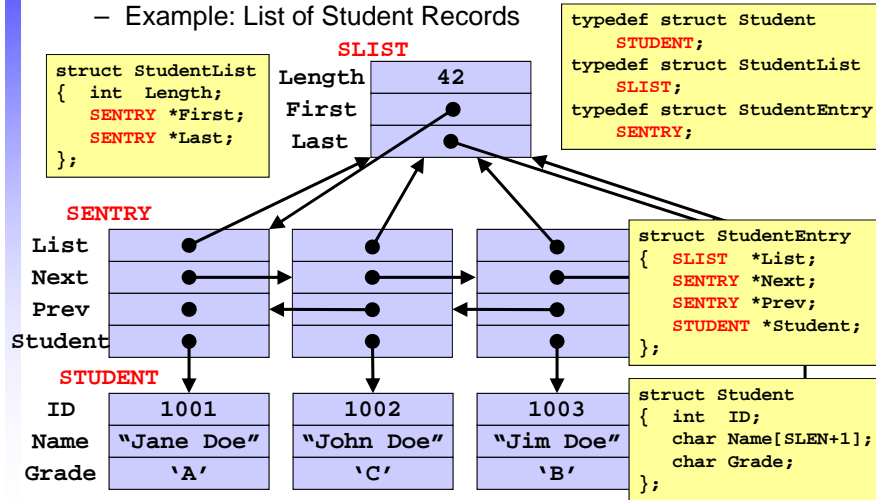
The diagram shows a header node with fields Length (42), First, and Last. The list contains 42 nodes. The first three nodes point to records with IDs 1001, 1002, and 1003. The 42nd node points to a record with ID 1042, Name 'Z End', and Grade 'A'. Ellipses indicate the presence of intermediate nodes between 1003 and 1042.

1. Empty list
2. Add a student
3. Append a student
4. Prepend a student
5. ...

EECS22: Advanced C Programming, Lecture 14
(c) 2013 R. Doemer
8

Dynamic Data Structures

- Double-Linked List (with header)
 - Example: List of Student Records



Dynamic Data Structures

- Example `student.h`

```

/* Student.h: header file for student records */

#ifndef STUDENT_H
#define STUDENT_H

#define SLEN 40

struct Student
{
  int ID;
  char Name[SLEN+1];
  char Grade;
};
typedef struct Student STUDENT;

/* allocate a new student record */
STUDENT *NewStudent(int ID, char *Name, char Grade);

/* delete a student record */
void DeleteStudent(STUDENT *s);

/* print a student record */
void PrintStudent(STUDENT *s);

#endif /* STUDENT_H */
  
```

Dynamic Data Structures

- Example `student.c` (part 1/3)

```

/* Student.c: maintaining student records */
#include "Student.h"
#include <stdlib.h>
#include <stdio.h>
#include <string.h>
#include <assert.h>

/* allocate a new student record */
STUDENT *NewStudent(int ID, char *Name, char Grade)
{
    STUDENT *s;
    s = malloc(sizeof(STUDENT));
    if (!s)
    {
        perror("Out of memory! Aborting...");
        exit(10);
    } /* fi */
    s->ID = ID;
    strncpy(s->Name, Name, SLEN);
    s->Name[SLEN] = '\0';
    s->Grade = Grade;
    return s;
} /* end of NewStudent */
...

```

EECS22: Advanced C Programming, Lecture 14

(c) 2013 R. Doemer

11

Dynamic Data Structures

- Example `student.c` (part 2/3)

```

...

/* delete a student record */
void DeleteStudent(STUDENT *s)
{
    assert(s);
    free(s);
} /* end of DeleteStudent */

/* print a student record */
void PrintStudent(STUDENT *s)
{
    assert(s);
    printf("Student ID:    %d\n", s->ID);
    printf("Student Name:  %s\n", s->Name);
    printf("Student Grade: %c\n", s->Grade);
} /* end of PrintStudent */

...

```

EECS22: Advanced C Programming, Lecture 14

(c) 2013 R. Doemer

12

Dynamic Data Structures

- Example `student.c` (part 3/3)

```

...
#ifdef MAIN /* test the student record functions */
int main(void)
{
    STUDENT *s1 = NULL, *s2 = NULL;
    printf("Creating 2 student records...\n");
    s1 = NewStudent(1001, "Jane Doe", 'A');
    s2 = NewStudent(1002, "John Doe", 'C');

    printf("Printing the student records...\n");
    PrintStudent(s1);
    PrintStudent(s2);

    printf("Deleting the student records...\n");
    DeleteStudent(s1);
    s1 = NULL;
    DeleteStudent(s2);
    s2 = NULL;

    printf("Done.\n");
    return 0;
} /* end of main */
#endif /* MAIN */
/* EOF */

```

EECS22: Advanced C Programming, Lecture 14

(c) 2013 R. Doemer

13

Dynamic Data Structures

- Example `Makefile` (part 1/2)

```

# Makefile: Student Records

# macro definitions
CC = gcc
DEBUG = -g
#DEBUG = -O2
CFLAGS = -Wall -ansi $(DEBUG) -c
LFLAGS = -Wall -ansi $(DEBUG)
MAIN = -DMAIN

# dummy targets
all: student StudentList

test: all
    valgrind student
    valgrind StudentList

clean:
    rm -f *.o
    rm -f student StudentList

...

```

EECS22: Advanced C Programming, Lecture 14

(c) 2013 R. Doemer

14

Dynamic Data Structures

- Example **Makefile** (part 2/2)

```

...
# compilation rules
Student.o: Student.c Student.h
    $(CC) $(CFLAGS) Student.c -o Student.o

Student: Student.c Student.h
    $(CC) $(MAIN) $(LFLAGS) Student.c -o Student

StudentList.o: StudentList.c StudentList.h Student.h
    $(CC) $(CFLAGS) Student.c -o StudentList.o

StudentList: StudentList.c StudentList.h Student.h Student.o
    $(CC) $(MAIN) $(LFLAGS) StudentList.c Student.o \
        -o StudentList

# EOF

```

EECS22: Advanced C Programming, Lecture 14

(c) 2013 R. Doemer

15

Dynamic Data Structures

- Example **studentList.h** (part 1/2)

```

/* StudentList.h: header file for lists of student records */
#ifndef STUDENT_LIST_H
#define STUDENT_LIST_H

#include "Student.h"

typedef struct StudentList SLIST;
typedef struct StudentEntry SENTRY;

struct StudentList
{
    int Length;
    SENTRY *First;
    SENTRY *Last;
};

struct StudentEntry
{
    SLIST *List;
    SENTRY *Next;
    SENTRY *Prev;
    STUDENT *Student;
};

...

```

EECS22: Advanced C Programming, Lecture 14

(c) 2013 R. Doemer

16

Dynamic Data Structures

- Example `studentList.h` (part 2/2)

```

...
/* allocate a new student list */
SLIST *NewStudentList(void);

/* delete a student list (and all entries) */
void DeleteStudentList(SLIST *l);

/* append a student at end of list */
void AppendStudent(SLIST *l, STUDENT *s);

/* prepend a student at beginning of list */
void PrependStudent(SLIST *l, STUDENT *s);

/* remove the first student from the list */
STUDENT *RemoveFirstStudent(SLIST *l);

/* remove the last student from the list */
STUDENT *RemoveLastStudent(SLIST *l);

/* print a student list */
void PrintStudentList(SLIST *l);

#endif /* STUDENT_LIST_H */

/* EOF */

```

EECS22: Advanced C Programming, Lecture 14

(c) 2013 R. Doemer

17

Dynamic Data Structures

- Example `studentList.c` (part 1/9)

```

/* StudentList.c: maintaining lists of student records */

#include "StudentList.h"
#include <stdlib.h>
#include <stdio.h>
#include <string.h>
#include <assert.h>

/* allocate a new student entry */
static SENTRY *NewStudentEntry(STUDENT *s)
{
    SENTRY *e;
    e = malloc(sizeof(SENTRY));
    if (! e)
        { perror("Out of memory! Aborting...");
          exit(10);
        } /* fi */
    e->List = NULL;
    e->Next = NULL;
    e->Prev = NULL;
    e->Student = s;
    return e;
} /* end of NewStudentEntry */

...

```

EECS22: Advanced C Programming, Lecture 14

(c) 2013 R. Doemer

18

Dynamic Data Structures

- Example `studentList.c` (part 2/9)

```

.../* delete a student entry */
static STUDENT *DeleteStudentEntry(SENTRY *e)
{
    STUDENT *s;
    assert(e);
    s = e->Student;
    free(e);
    return s;
} /* end of DeleteStudentEntry */

/* allocate a new student list */
SLIST *NewStudentList(void)
{
    SLIST *l;
    l = malloc(sizeof(SLIST));
    if (! l)
        { perror("Out of memory! Aborting...");
          exit(10);
        } /* fi */
    l->Length = 0;
    l->First = NULL;
    l->Last = NULL;
    return l;
} /* end of NewStudentList */
...

```

EECS22: Advanced C Programming, Lecture 14

(c) 2013 R. Doemer 19

Dynamic Data Structures

- Example `studentList.c` (part 3/9)

```

...
/* delete a student list (and all entries) */
void DeleteStudentList(SLIST *l)
{
    SENTRY *e, *n;
    STUDENT *s;

    assert(l);
    e = l->First;
    while(e)
        { n = e->Next;
          s = DeleteStudentEntry(e);
          DeleteStudent(s);
          e = n;
        }
    free(l);
} /* end of DeleteStudentList */
...

```

EECS22: Advanced C Programming, Lecture 14

(c) 2013 R. Doemer

20

Dynamic Data Structures

- Example `studentList.c` (part 4/9)

```

.../* append a student at end of list */
void AppendStudent(SLIST *l, STUDENT *s)
{
    SENTRY *e = NULL;
    assert(l);
    assert(s);
    e = NewStudentEntry(s);
    if (l->Last)
    {
        e->List = l;
        e->Next = NULL;
        e->Prev = l->Last;
        l->Last->Next = e;
        l->Last = e;
    }
    else
    {
        e->List = l;
        e->Next = NULL;
        e->Prev = NULL;
        l->First = e;
        l->Last = e;
    }
    l->Length++;
} /* end of AppendStudent */
...

```

EECS

Dynamic Data Structures

- Example `studentList.c` (part 5/9)

```

.../* prepend a student at beginning of list */
void PrependStudent(SLIST *l, STUDENT *s)
{
    SENTRY *e = NULL;
    assert(l);
    assert(s);
    e = NewStudentEntry(s);
    if (l->First)
    {
        e->List = l;
        e->Next = l->First;
        e->Prev = NULL;
        l->First->Prev = e;
        l->First = e;
    }
    else
    {
        e->List = l;
        e->Next = NULL;
        e->Prev = NULL;
        l->First = e;
        l->Last = e;
    }
    l->Length++;
} /* end of PrependStudent */
...

```

EECS

Dynamic Data Structures

- Example `studentList.c` (part 6/9)

```

.../* remove the first student from the list */
STUDENT *RemoveFirstStudent(SLIST *l)
{
    SENTRY *e = NULL;
    assert(l);
    if (l->First)
    {
        e = l->First;
        l->First = e->Next;
        if (l->First)
        {
            l->First->Prev = NULL;
        }
        else
        {
            assert(l->Last == e);
            l->Last = NULL;
        }
        l->Length--;
        return DeleteStudentEntry(e);
    }
    else
    {
        return(NULL);
    }
} /* end of RemoveFirstStudent */
...

```

EECS22: Advanced C Programming, Lecture 14

(c) 2013 R. Doemer

23

Dynamic Data Structures

- Example `studentList.c` (part 7/9)

```

.../* remove the last student from the list */
STUDENT *RemoveLastStudent(SLIST *l)
{
    SENTRY *e = NULL;
    assert(l);
    if (l->Last)
    {
        e = l->Last;
        l->Last = e->Prev;
        if (l->Last)
        {
            l->Last->Next = NULL;
        }
        else
        {
            assert(l->First == e);
            l->First = NULL;
        }
        l->Length--;
        return DeleteStudentEntry(e);
    }
    else
    {
        return(NULL);
    }
} /* end of RemoveLastStudent */
...

```

EECS22: Advanced C Programming, Lecture 14

(c) 2013 R. Doemer

24

Dynamic Data Structures

- Example `studentList.c` (part 8/9)

```

...

/* print a student list */
void PrintStudentList(SLIST *l)
{
    SENTRY *e;
    assert(l);
    e = l->First;
    while(e)
    { PrintStudent(e->Student);
      e = e->Next;
    }
} /* end of PrintStudentList */

...

```

Dynamic Data Structures

- Example `studentList.c` (part 9/9)

```

#ifdef MAIN
int main(void)
{
    STUDENT *s = NULL;
    SLIST *l = NULL;
    l = NewStudentList();
    s = NewStudent(1001, "Jane Doe", 'A');
    AppendStudent(l, s);
    s = NewStudent(1002, "John Doe", 'C');
    AppendStudent(l, s);
    s = NewStudent(1000, "New Kid", 'F');
    PrependStudent(l, s);
    PrintStudentList(l);
    s = RemoveFirstStudent(l);
    AppendStudent(l, s);
    s = RemoveLastStudent(l);
    PrependStudent(l, s);
    DeleteStudentList(l);
    l = NULL;
    return 0;
} /* end of main */
#endif /* MAIN */
/* EOF */

```

Dynamic Data Structures

- Example Session

```
% vi StudentList.c
% vi Makefile
% make
gcc -Wall -ansi -g -c Student.c -o Student.o
gcc -DMAIN -Wall -ansi -g StudentList.c Student.o -o StudentList
% valgrind StudentList
==5908== Memcheck, a memory error detector
Student ID: 1000
Student Name: New Kid
Student Grade: F
Student ID: 1001
Student Name: Jane Doe
Student Grade: A
Student ID: 1002
Student Name: John Doe
Student Grade: C
==5908== HEAP SUMMARY:
==5908==   in use at exit: 0 bytes in 0 blocks
==5908== total heap usage: 9 allocs, 9 frees, 328 bytes allocated
==5908== All heap blocks were freed -- no leaks are possible
==5908== ERROR SUMMARY: 0 errors from 0 contexts
%
```