EECS 22: Advanced C Programming

Lecture 15 (TuTh)

Rainer Dömer

doemer@uci.edu

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

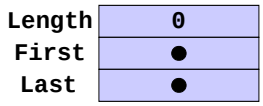
Part 1: Overview

- Dynamic Data Structures
  - Double-linked List
    - Append and prepend operations
    - Remove first and last entries
  - Example: List of student records (continued)
    - **`Student.h`**
    - **`Student.c`**
    - **`StudentList.h`**
    - **`StudentList.c`**
    - **`Makefile`**

Dynamic Data Structures

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

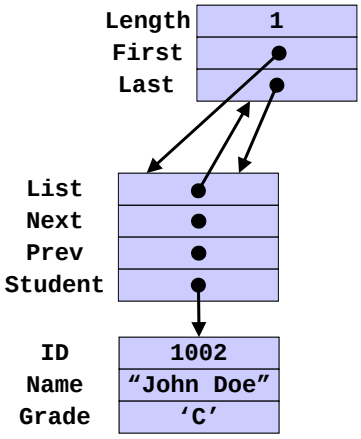
1. Empty list



Dynamic Data Structures

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

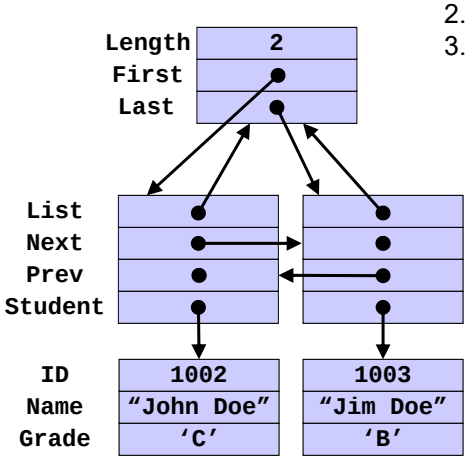
1. Empty list
2. Add a student



Dynamic Data Structures

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

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



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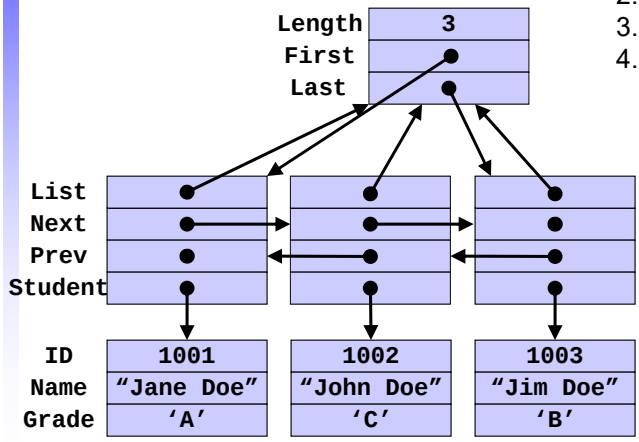
Dynamic Data Structures

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

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



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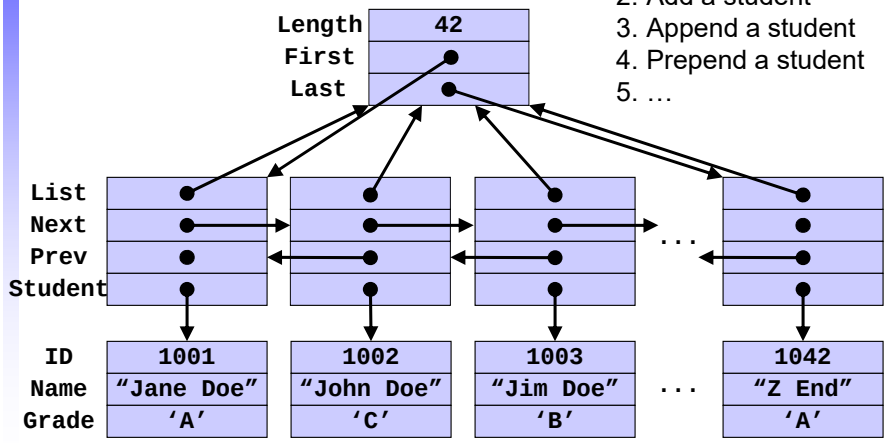
Dynamic Data Structures

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

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

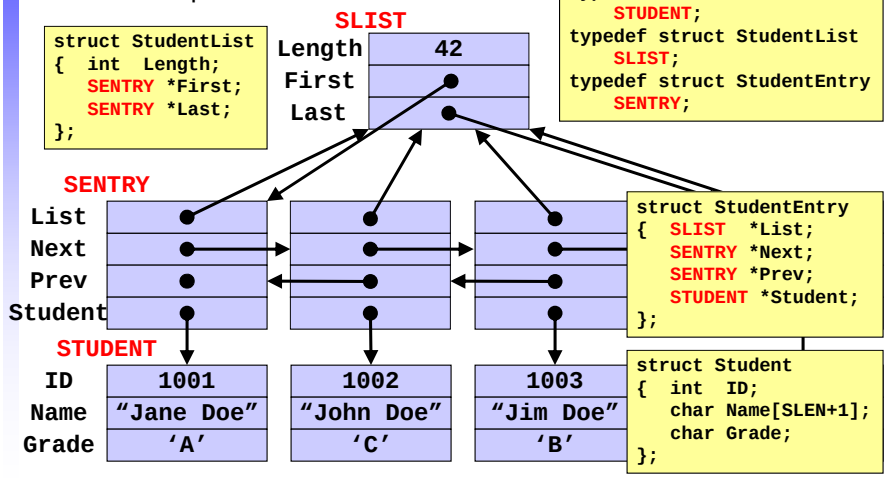


Dynamic Data Structures

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

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

```
typedef struct Student
    STUDENT;
typedef struct StudentList
    SLIST;
typedef struct StudentEntry
    SENTRY;
```




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

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

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 **`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;
};

...
```

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 */
```


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 */
...
```

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 */
...
```


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 */
...
```

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 */
...
```

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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 */
...
```

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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 */
...
```


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 */
...
```

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
% make
gcc -Wall -ansi –std=c99 -g -c Student.c -o Student.o
gcc -DMAIN -Wall -ansi –std=c99 -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
%
```


Part 2: Overview

- Dynamic Data Structures
  - Double-linked list
    - Element insertion before another list element
    - Element insertion after another list element
    - Element deletion (left for exercise at home)
  - Example: Student records
    - **`StudentList.h, StudentList.c`**
      - New **`InsertStudentBefore`**
      - New **`InsertStudentAfter`**
- Data Display Debugger
  - Graphical data structure display in **`ddd`**

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;
};

...
```


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);

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

/* insert a student before/after an existing one */
void InsertStudentBefore(SENTRY *e, STUDENT *s);
void InsertStudentAfter(SENTRY *e, STUDENT *s);

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

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

#endif /* STUDENT_LIST_H */

/* EOF */
```

Dynamic Data Structures

- Example **`StudentList.c`** (part 1/4)

```
/* StudentList.c: maintaining lists of student records  */
/* author: Rainer Doemer                                */
/* modifications:                                       */
/* 11/10/11 RD added InsertStudentBefore, InsertStudentAfter */
/* 11/08/11 RD version for double-linked lists          */
/* 11/03/11 RD initial version                          */

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

/* unmodified functions omitted here for brevity */

...
```


Dynamic Data Structures

- Example **`StudentList.c`** (part 2/4)

```
...

/* insert a student before an existing one */
void InsertStudentBefore(SENTRY *e, STUDENT *s)
{
    SENTRY *New;
    New = NewStudentEntry(s);
    New->List = e->List;
    New->Next = e;
    New->Prev = e->Prev;
    e->Prev = New;
    if (New->Prev)
      { New->Prev->Next = New;
      }
    else
      { assert(New->List->First == e);
        New->List->First = New;
      }
    New->List->Length++;
} /* end of InsertStudentBefore */

...
```

Dynamic Data Structures

- Example **`StudentList.c`** (part 3/4)

```
...

/* insert a student after an existing one */
void InsertStudentAfter(SENTRY *e, STUDENT *s)
{
    SENTRY *New;
    New = NewStudentEntry(s);
    New->List = e->List;
    New->Next = e->Next;
    New->Prev = e;
    e->Next = New;
    if (New->Next)
      { New->Next->Prev = New;
      }
    else
      { assert(New->List->Last == e);
        New->List->Last = New;
      }
    New->List->Length++;
} /* end of InsertStudentAfter */

...
```


Dynamic Data Structures

- Example **`StudentList.c`** (part 4/4)

```
#ifdef MAIN
int main(void)
STUDENT *s = NULL;
    SLIST *l = NULL;
    SENTRY *e = NULL;
    l = NewStudentList();
    s = NewStudent(1002, "Jim Doe", 'B');
    AppendStudent(l, s);
    e = l->First;
    assert(e->Student == s);
    s = NewStudent(1003, "John Doe", 'C');
    InsertStudentAfter(e, s);
    s = NewStudent(1001, “Jane Doe", 'A');
    InsertStudentBefore(e, s);

    PrintStudentList(l);

    DeleteStudentList(l);
    l = NULL;
    return 0;
} /* end of main */
#endif /* MAIN */
/* EOF */
```

Dynamic Data Structures

- Example Session

```
% vi StudentList.c
% vi Makefile
% make
gcc -DMAIN -Wall -ansi –std=c99 -g StudentList.c Student.o
        -o StudentList
% valgrind ./StudentList
==5908== Memcheck, a memory error detector
Student ID:    1001
Student Name:  Jane Doe
Student Grade: A
Student ID:    1002
Student Name:  Jim Doe
Student Grade: B
Student ID:    1003
Student Name:  John Doe
Student Grade: C
==5908== HEAP SUMMARY:
==5908==    in use at exit: 0 bytes in 0 blocks
==5908==  total heap usage: 7 allocs, 7 frees, 264 bytes allocated
==5908== All heap blocks were freed -- no leaks are possible
==5908== ERROR SUMMARY: 0 errors from 0 contexts
%
```


Graphical Data Structure Display

- Data Display Debugger **ddd**
  - Graphical frontend for GDB
    - Requires *X* forwarding client (e.g. *Xming* in addition to *Putty*)
  - Displays separate windows
    - Menu bar and command buttons
    - ➢ Graphical display area for *pointers* and *data structures*!
    - Source code (and assembly code) browser
    - Command line interface
  - ➢ Can display data structures built by pointers as graphs
    - Very useful tool to visualize and debug dynamic data structures
  - Example: **`StudentList.c`**

```
% vi StudentList.c
% make StudentList
gcc –Wall –ansi –std=c99 –g –c Student.c –o Student.o
gcc -DMAIN -Wall -ansi –std=c99 -g StudentList.c Student.o
        -o StudentList
% ddd ./StudentList
```

Graphical Data Structure Display