

# EECS 22: Advanced C Programming

## Lecture 16

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## Lecture 16: Overview

- Pointers to Functions
- Dynamic Data Structures
  - Sorted Double-linked List
  - Insertion Sort
  - Example: Student records
    - `student.h`
    - `studentList.h`
    - `studentSort.h`
    - `studentSort.c`
    - `Makefile`

## Pointers to Functions

- In C, a Function is an Object...
  - ... with a name, a type, and a location (just like a variable)
  - ... but without a value or size (meaningless for functions)
- The Address of a Function...
  - ... is the address of its first instruction in memory
  - ... can be obtained with the *address-of* operator (`&fct`)
- Function Pointers...
  - ... can be declared, defined, and initialized
  - ... can be assigned to point to defined functions
  - ... can be assigned to other pointers (of the same type)
  - ... can be passed as arguments to and from functions
  - ... can be used to call the referenced function

## Pointers to Functions

- Example:

```

/* function definitions */
int add(int a, int b)
{ return a + b;
}

int multiply(int a, int b)
{ return a * b;
}

/* type definition for a pointer to a function */
typedef int (*t_OP)(int a, int b);

int main(void)
{ int n = 0;
  t_OP op = NULL; /* function pointer */

  op = &add; /* set pointer to add */
  n = (*op)(4, 17); /* call function via pointer */

  op = multiply; /* set pointer to multiply */
  n = op(2, n); /* call function via pointer */

  return n;
}

```

## Dynamic Data Structures

- **Sorted** Double-Linked List
  - Example: List of Student Records **sorted by ID**

Length	42
First	●
Last	●

List	●	●	●	●
Next	→	→	→	→
Prev	←	←	←	←
Student	↓	↓	↓	↓

ID	1001	1002	1003	...	1042
Name	"John Doe"	"Jane Doe"	"Jim Doe"	...	"Z End"
Grade	'B'	'A'	'C'	...	'A'

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## Dynamic Data Structures

- **Sorted** Double-Linked List
  - Example: List of Student Records **sorted by Name**

Length	42
First	●
Last	●

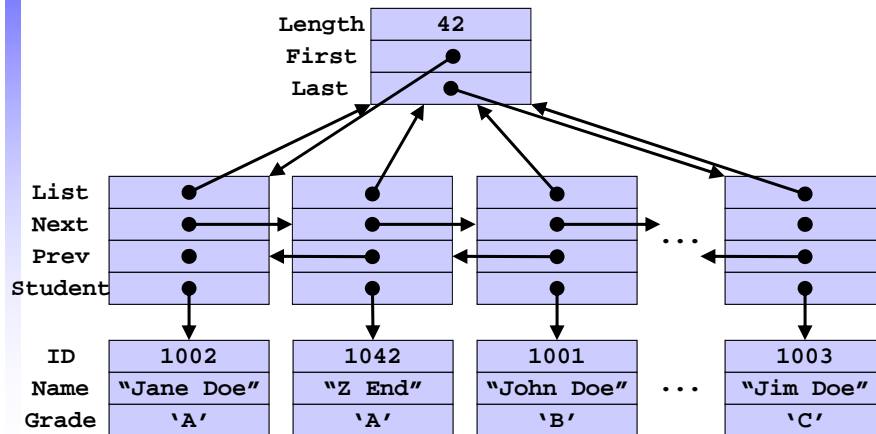
List	●	●	●	●
Next	→	→	→	→
Prev	←	←	←	←
Student	↓	↓	↓	↓

ID	1002	1003	1001	...	1042
Name	"Jane Doe"	"Jim Doe"	"John Doe"	...	"Z End"
Grade	'A'	'C'	'B'	...	'A'

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## Dynamic Data Structures

- **Sorted Double-Linked List**
  - Example: List of Student Records **sorted by Grade**



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## Dynamic Data Structures

- **Sorting**
  - A very well-studied topic in computer science!
  - Many algorithms exist
    - Bubble Sort
    - Insertion Sort
    - Quick Sort
    - Heap Sort, ...
  - For data stored in a linked list, *Insertion Sort* is a simple and effective solution
    - Start with an empty list
    - Insert items one by one while maintaining the sorted order
      - Traverse the list and compare the item with the list elements as long as the *sorting property* holds
      - Then insert the item as a new list element at this position
    - Searching an item in a sorted list is twice as fast on average!

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## Dynamic Data Structures

- Insertion Sort, Algorithm:
  - Start with an empty list
  - Insert items one by one while maintaining the sorted order
    - Traverse the list and compare the item with the list elements as long as the *sorting property* holds
    - Then insert the item as a new list element at this position
- Insertion Sort, Pseudo Code:
  - **InsertionSort** (*List L*)
    - Set List  $L2 = \{ \}$
    - For each unsorted item  $i \in L$ :
      - » *InsertItem* ( $L2, i$ )
    - Return  $L2$
  - **InsertItem** (*List L, Item i*)
    - Repeat  $e = \text{NextElement}(L)$  until  $i < e$ ;
    - Insert  $i$  before  $e$  into  $L$

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## Dynamic Data Structures

- Insertion Sort, Pseudo Code:
  - **InsertionSort** (*List L*)
    - Set List  $L2 = \{ \}$
    - For each unsorted item  $i \in L$ :
      - » *InsertItem* ( $L2, i$ )
    - Return  $L2$
  - **InsertItem** (*List L, Item i*)
    - Repeat  $e = \text{NextElement}(L)$  until  $i < e$ ;
    - Insert  $i$  before  $e$  into  $L$
- To sort for a different criteria, only the comparison changes!

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## Dynamic Data Structures

- Insertion Sort, Pseudo Code:
  - **InsertionSort** (*List L*, *CompareFct*)
    - Set List L2 = {}
    - For each unsorted item  $i \in L$ :
      - » *InsertItem* (L2,  $i$ , *CompareFct*)
    - Return L2
  - **InsertItem** (*List L*, *Item i*, *CompareFct*)
    - Repeat  $e = \text{NextElement}(L)$  until *CompareFct*( $i$ ,  $e$ );
    - Insert  $i$  before  $e$  into  $L$
- To sort for a different criteria, only the comparison changes!
- Instead of implementing many different sort functions, we can make the *comparison* operation a *parameter*!
- Pass a *pointer to the comparison function* to the sort function!

## 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;
};

...

```

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## 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 */

```

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## Dynamic Data Structures

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

```

/* StudentSort.h: header file for sorted student records */
#ifndef STUDENT_SORT_H
#define STUDENT_SORT_H

#include "Student.h"
#include "StudentList.h"

typedef int CMP_F(STUDENT *s1, STUDENT *s2);

/* compare students by ID */
int CompareStudentID(STUDENT *s1, STUDENT *s2);

/* compare students by name */
int CompareStudentName(STUDENT *s1, STUDENT *s2);

/* compare students by grade */
int CompareStudentGrade(STUDENT *s1, STUDENT *s2);

...

```

## Dynamic Data Structures

- Example **StudentSort.h** (part 2/2)

```

...

/* sort a student list */
SLIST *SortStudentList(SLIST *l, CMP_F *CompareFct);

/* find a student by ID in a sorted list */
STUDENT *FindStudentID(SLIST *l, int ID);

/* find a student by name in a sorted list */
STUDENT *FindStudentName(SLIST *l, char *Name);

/* insert a student into a sorted list */
void InsertStudent(SLIST *l, STUDENT *s, CMP_F *CompareFct);

#endif /* STUDENT_SORT_H */

/* EOF */

```



## Dynamic Data Structures

- Example `StudentSort.c` (part 1/8)

```

/* StudentSort.c: sorting student records (by various criteria) */

#include "StudentSort.h"

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

/* compare students by ID */
int CompareStudentID(STUDENT *s1, STUDENT *s2)
{
    assert(s1);
    assert(s2);
    return(s1->ID - s2->ID);
} /* end of CompareStudentID */

...

```

## Dynamic Data Structures

- Example `StudentSort.c` (part 2/8)

```

...

/* compare students by name */
int CompareStudentName(STUDENT *s1, STUDENT *s2)
{
    assert(s1);
    assert(s2);
    return(strcmp(s1->Name, s2->Name));
} /* end of CompareStudentName */

/* compare students by grade */
int CompareStudentGrade(STUDENT *s1, STUDENT *s2)
{
    assert(s1);
    assert(s2);
    return(s1->Grade - s2->Grade);
} /* end of CompareStudentGrade */

...

```

## Dynamic Data Structures

- Example `StudentSort.c` (part 3/8)

```

...
/* sort a student list (insertion sort) */
SLIST *SortStudentList(SLIST *l, CMP_F *CompareFct)
{
    SLIST *l2 = NULL;
    STUDENT *s = NULL;

    assert(l);
    assert(CompareFct);
    l2 = NewStudentList();
    while((s = RemoveFirstStudent(l)))
        { InsertStudent(l2, s, CompareFct);
        }
    assert(l->Length == 0);
    DeleteStudentList(l);
    return(l2);
} /* end of SortStudentList */
...

```

## Dynamic Data Structures

- Example `StudentSort.c` (part 4/8)

```

...
/* find a student by ID in a sorted list */
STUDENT *FindStudentID(SLIST *l, int ID)
{
    SENTRY *e;
    assert(l);
    e = l->First;
    while(e)
        { if (e->Student->ID == ID)
          { return(e->Student);
          }
          if (e->Student->ID > ID)
            { break;
            }
          e = e->Next;
        }
    return(NULL);
} /* end of FindStudentID */
...

```

## Dynamic Data Structures

- Example `StudentSort.c` (part 5/8)

```

...
/* find a student by name in a sorted list */
STUDENT *FindStudentName(SLIST *l, char *Name)
{
    SENTRY *e;
    int CompVal;
    assert(l);
    assert(Name);
    e = l->First;
    while(e)
        { CompVal = strcmp(e->Student->Name, Name);
          if (CompVal == 0)
              { return(e->Student);
            }
          if (CompVal > 0)
              { break;
            }
          e = e->Next;
        }
    return(NULL);
} /* end of FindStudentName */
...

```

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## Dynamic Data Structures

- Example `StudentSort.c` (part 6/8)

```

...
/* insert a student into a sorted list */
void InsertStudent(SLIST *l, STUDENT *s, CMP_F *CompareFct)
{
    SENTRY *e = NULL;
    assert(l);
    assert(s);
    assert(CompareFct);
    e = l->First;
    while(e)
        { if (CompareFct(e->Student, s) > 0)
          { break;
            }
          e = e->Next;
        }
    if (e)
        { InsertStudentBefore(e, s); }
    else
        { AppendStudent(l, s); }
} /* end of InsertStudent */
...

```

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## Dynamic Data Structures

- Example `StudentSort.c` (part 7/8)

```

...
#ifdef MAIN
int main(void)
{
    SLIST *l = NULL;
    l = NewStudentList();
    AppendStudent(l, NewStudent(1001, "Jane Doe", 'A'));
    AppendStudent(l, NewStudent(1002, "John Doe", 'C'));
    AppendStudent(l, NewStudent(1000, "New Kid", 'F'));
    AppendStudent(l, NewStudent(1003, "Jane Doe", 'B'));
    AppendStudent(l, NewStudent(1009, "Z End", 'A'));
    AppendStudent(l, NewStudent(1008, "Alice A", 'A'));
    AppendStudent(l, NewStudent(1007, "Bob B", 'B'));
    AppendStudent(l, NewStudent(1006, "Carl C", 'C'));
    AppendStudent(l, NewStudent(1005, "Dave D", 'D'));
    AppendStudent(l, NewStudent(1004, "Eve E", 'F'));

    printf("1. Initial unsorted student list:\n");
    PrintStudentList(l);
}
...

```

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## Dynamic Data Structures

- Example `StudentSort.c` (part 8/8)

```

...
printf("2. Student list sorted by name:\n");
l = SortStudentList(l, CompareStudentName);
PrintStudentList(l);
assert(FindStudentName(l, "John Doe") != NULL);
assert(FindStudentName(l, "No Body") == NULL);

printf("3. Student list sorted by ID:\n");
l = SortStudentList(l, CompareStudentID);
PrintStudentList(l);
assert(FindStudentID(l, 1005) != NULL);
assert(FindStudentID(l, 1999) == NULL);

printf("4. Student list sorted by grade:\n");
l = SortStudentList(l, CompareStudentGrade);
PrintStudentList(l);

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

```

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## 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 StudentSort

test: all
    valgrind Student
    valgrind StudentList
    valgrind StudentSort

clean:
    rm -f *.o
    rm -f Student StudentList StudentSort
...
```

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## 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) StudentList.c -o StudentList.o

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

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

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

# EOF
```

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## Dynamic Data Structures

- Example Session

```
% vi StudentSort.c
% vi Makefile
% make
gcc -DMAIN -Wall -ansi -g Student.c -o Student
gcc -Wall -ansi -g -c Student.c -o Student.o
gcc -DMAIN -Wall -ansi -g StudentList.c Student.o -o StudentList
gcc -Wall -ansi -g -c StudentList.c -o StudentList.o
gcc -DMAIN -Wall -ansi -g StudentSort.c StudentList.o Student.o \
    -o StudentSort
% StudentSort
1. Initial unsorted student list:
Student ID: 1001
Student Name: Jane Doe
Student Grade: A
Student ID: 1002
Student Name: John Doe
...
Student Grade: D
Student ID: 1004
Student Name: Eve E
Student Grade: F
...
```

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## Dynamic Data Structures

- Example Session

```
...
2. Student list sorted by name:
Student ID: 1008
Student Name: Alice A
Student Grade: A
Student ID: 1007
Student Name: Bob B
Student Grade: B
Student ID: 1006
Student Name: Carl C
Student Grade: C
Student ID: 1005
Student Name: Dave D
Student Grade: D
...
Student ID: 1000
Student Name: New Kid
Student Grade: F
Student ID: 1009
Student Name: Z End
Student Grade: A
...
```

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## Dynamic Data Structures

- Example Session

```

...
3. Student list sorted by ID:
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
Student ID: 1003
Student Name: Jane Doe
Student Grade: B
...
Student ID: 1008
Student Name: Alice A
Student Grade: A
Student ID: 1009
Student Name: Z End
Student Grade: A
...

```

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## Dynamic Data Structures

- Example Session

```

...
4. Student list sorted by grade:
Student ID: 1001
Student Name: Jane Doe
Student Grade: A
Student ID: 1008
Student Name: Alice A
Student Grade: A
Student ID: 1009
Student Name: Z End
Student Grade: A
Student ID: 1003
Student Name: Jane Doe
Student Grade: B
Student ID: 1007
Student Name: Bob B
...
Student ID: 1004
Student Name: Eve E
Student Grade: F
%

```

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