Welcome

CS1101S Studio Session Week 8:
Data Structure Design & Stateful Programming

Niu Yunpeng

niuyunpeng@u.nus.edu

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Overview

1. Data structure design
    - Design principle
    - Examples
2. Stateful programming
    - Mutable data
    - Mutable data structure

Data Structure Design

Three steps to implement a program

In order to solve a problem using a program, you need:

- Think of an appropriate algorithm;
- Design a suitable data structure;
- Do the coding (with good coding style).

Data Structure Design

Thus...

The first three CS modules are:

- CS1101S Programming Methodology
- CS2030 Programming Methodology II
- CS2040 Data Structures and Algorithms

Data Structure Design

Data structure

- In computer science, a data structure is a particular way of organizing data in a computer so that it can be used efficiently.

Algorithm

- In computer science, an algorithm is a self-contained sequence of actions to be performed.

Data Structure Design

Data & information

- Data is the storage of information.
- Two kinds of information: **states** & **procedures**.

Data structure & algorithm

- *To store states efficiently:* use **data structure**;
- *To perform procedures efficiently:* use **algorithm**.

Data Structure Design

Design principle of data structure

- Understand the requirement before doing the actual design;
- Separate the interface from the implementation;
- Compare the advantage and tradeoff;
- Principle of last commitment.

Data Structure Design

1. Understand the requirement

- Your data structure do not need to support everything. You only need to implement what the users really need. Anything else should not be considered.
- There is no “bonus point”.

Data Structure Design

2. Separate the interface from the implementation

- You are free to choose how you are going to implement the data structure, like choice of programming language, abstract data type (ADT), etc.
- However, the interface given to the users should always be the same (and accorded with the convention).
- In other words, users do not need to care about the implementation.

Data Structure Design

3. Compare the advantage and tradeoff

- You may have many choices available to implement the same data structure (or the interface).
- Usually, each of them has its own advantages and tradeoffs.
- You should compare which operation is used more frequently so as to make the final decision.

Data Structure Design

4. Principle of last commitment

- Whenever possible, delay decisions until you have enough information, or until the choice becomes inevitable.
- Make sure your implementation is as generic as possible.
- Try to enhance program re-usability.

Data Structure Design

Examples of data structure so far...

- Coin change
- Symbolic differentiation
- Rational number
- Complex number
- Pair/list/tree
- Set
- ...

Data Structure Design

Common pattern of these examples

- Constructor
- Accessor
- Predicate
- Printer
- ...

Data Structure Design

Advanced data structure & algorithm modules

- CS3230 Design and Analysis of Algorithms
- CS4234 Optimisation Algorithms
- CS5234 Combinatorial and Graph Algorithms
- CS5330 Randomized Algorithms
- CS6234 Advanced Algorithms

Caution

- Could be interesting *(at least to some of you)*
- Need in-depth understanding

Overview

1. Data structure design
   - Design principle
   - Examples
2. Stateful programming
   - Mutable data
   - Mutable data structure

Stateful Programming

Immutable

- A constant holds a value inside it.
- `const x = 1;`
- Cannot hold another value.

Mutable

- A new value can be assigned to the same variable.
- `<variable_name> = <new_value>`
- `let y = 2;`
- To change the value inside `y = 3;`

Stateful Programming

Before Week 8

- Pure functional programming.
- Substitution model.
- Return value do not change if values of arguments are the same.

After Week 8

- Stateful programming.
- Environment model.
- Return value may vary even if values of arguments are the same.

Stateful Programming

The concept of memory allocation

- When we define a variable, the interpreter will allocate a position in memory (random access memory, RAM) randomly so that we can use it any time we want.
- The name is actually the reference to this position in memory.
- Whenever we call the name, the interpreter will just look for the value stored at that position in memory.

Understanding

- A variable is like a **changeable container**.

Stateful Programming

Why can we change the value of a variable?

- Before, when we want to have a new value of a variable, we allocate a new position in memory.
- However, it is not necessary for us to do this at all (because this is in fact a waste of space in memory).
- We can just update the value stored at the original position. When we call that name after that, the interpreter will still look up for the same position and a new value will be found.

Mutable Data Structure

Before today - immutable data structure

- A collection of data into one object.
- Data inside cannot be changed.
- Constructor, accessor, predicate, printer, ...

After today - mutable data structure

- A collection of data into one object.
- Data inside can be changed.
- Constructor, accessor (getter), mutator (setter), predicate, printer, ...

Mutable Data Structure

Mutable pair/list

- `set_head(pr, x)`: set the head of a pair to become `x`;
- `set_tail(pr, y)`: set the tail of a pair to become `y`.

Caution

- Remember identity & equality;
- Remember the concept of memory allocation.

Mutable Data Structure

Things you can do for pair/list

- Re-write some parts of the list library;
  - To make the functions more efficient with respect to time and/or space
- Create a cycle in a list.

Your task today

- Can you write a program to detect the number of cycles in a given list (or return 0 if none)?

Mutable Data Structure

Mutable data structure

- Linked list
- Double-way linked list
- Queue
- Stack
- Table
- ...

Mutable Data Structure

Linked list / double-way linked list 1

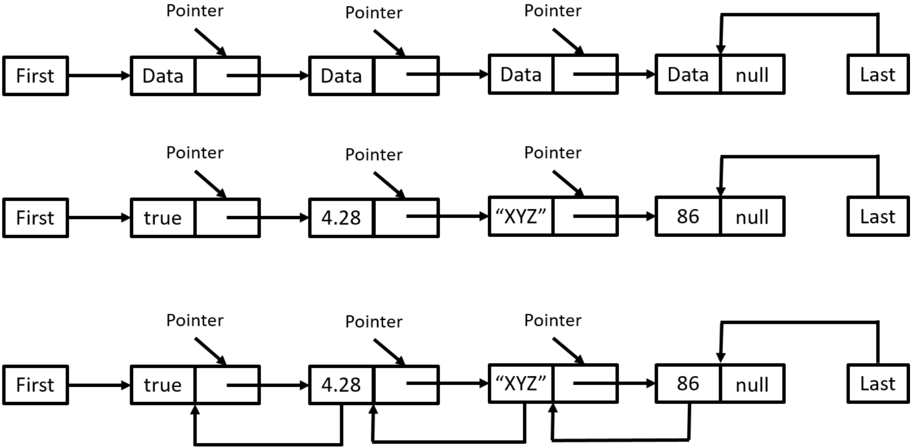
- `make_linked_list()`: create an empty linked list;
- `get_first(lst)`: get the first node of the linked list;
- `get_last(lst)`: get the first node of the linked list;
- `get_next(node)`: get the next node in the linked list;
- `get_prev(node)`: get the last node in the linked list;
- `get_data(node)`: get the data stored in the current node.

Mutable Data Structure

Linked list / double-way linked list 2

- `prepend(lst, x)`: add `x` to the front of the linked list;
- `append(lst, x)`: add `x` to the rear of the linked list;
- `add_before(node, x)`: add `x` before the node;
- `add_after(node, x)`: add `x` after the node;
- `remove_first(lst)`: delete the first node in the linked list;
- `remove_last(lst)`: delete the last node in the linked list;
- `delete(node)`: delete the selected node in the linkd list;
- `empty(lst)`: delete all items in the linked list;
- `is_empty_linked_list(lst)`: check if a linked list is empty.

Mutable Data Structure



Mutable Data Structure

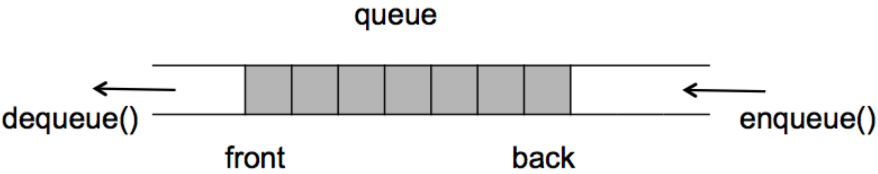
Queue - first in first out (FIFO)

- `make_queue()`: create an empty queue;
- `enqueue(queue, x)`: add `x` to the end of the queue;
- `dequeue(queue)`: delete the first item of the queue;
- `peek(queue)`: retrieve the value the first item of the queue;
- `empty(queue)`: delete all items in the queue;
- `is_empty_queue(queue)`: check if a queue is empty.

Notice

- `dequeue(queue)` and `peek(queue)` will raise an error if the queue is empty.

Mutable Data Structure



Mutable Data Structure

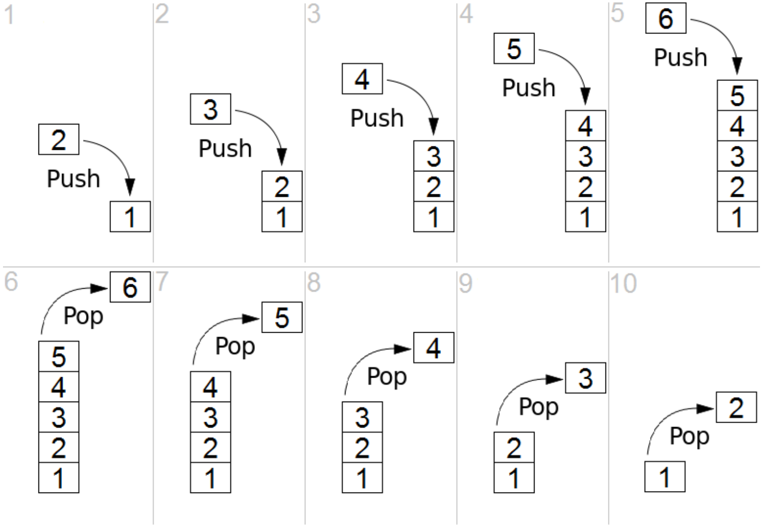
Stack - first in last out (FILO)

- `make_stack()`: create an empty stack;
- `push(stack, x)`: add `x` on the top of the stack;
- `pop(stack)`: delete the first item on the top of the stack;
- `peek(stack)`: retrieve the first value on the top of the stack;
- `empty(stack)`: delete all items in the stack;
- `is_empty_stack(stack)`: check if a stack is empty.

Notice

- `pop(stack)` and `peek(stack)` will raise an error if the stack is empty.

Mutable Data Structure



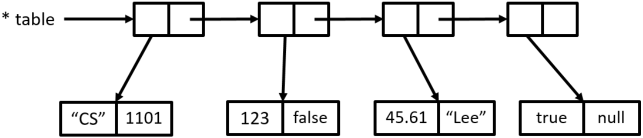
Mutable Data Structure

Table

- `make_table()`: create an empty table;
- `contains(key, table)`: check if the table contains this key;
- `put(key, value, table)`: insert a new entry to the table;
- `lookup(key, table)`: return the value corresponding to the specified key in the table, or `undefined` if the key is not found;
- `empty(table)`: delete all entries in the stack;
- `is_empty_table(table)`: check if a table is empty.

Mutable Data Structure

key	value
“CS”	1101
123	false
45.61	“Lee”
true	null
...	...



Mutable Data Structure

Usage of mutable data structure

- Stack:
    - The interpreter uses stack to implement recursion.
- Table:
    - The binding between names and values in a frame is a table;
    - Later, we will use table to implement memoization.

Robot Mission Demo

Let's do it now.

End

The End

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