Introduction to Data Structures

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Full History Recurrences (Cont.)

A Not So Simple Full-history Recurrence Relation

$$T(n) = n - 1 + \frac{2}{n}\sum_{i=1}^{n-1} T(i), \ \text{(for } n \geq 2); \ T(1) = 0.$$

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- **Idea:** Use the shifting and canceling terms technique, s.t., most of the $T(i)$ terms gets canceled out.

A Not So Simple Full-history Recurrence Relation (Cont.)

Multiplying both sides by n, we get:

$$\begin{aligned} nT(n) &= n(n-1) + 2\sum_{i=1}^{n-1} T(i), \\ (n+1)T(n+1) &= n(n+1) + 2\sum_{i=1}^{n} T(i). \end{aligned}$$

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Therefore,

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Expanding, we get

$$T(n) \leq 2 + \frac{n+1}{n}\left[2 + \frac{n}{n-1}\left[2 + \frac{n-1}{n-2}\left[\cdots \frac{4}{3}\right]\right]\right]$$

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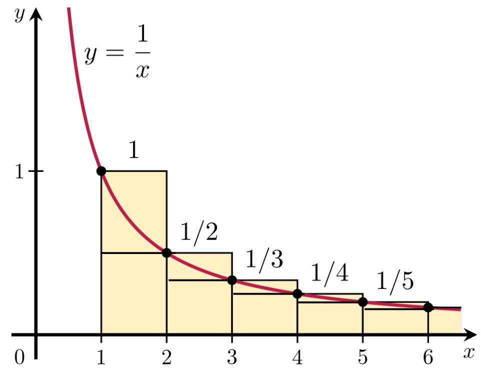
&= 2(n+1)\left[\frac{1}{n+1} + \frac{1}{n} + \frac{1}{n-1} + \frac{1}{n-2} + \cdots + \frac{1}{3}\right] \\
&= 2(n+1)(H(n+1) - 1.5);
\end{aligned}
$$

where $H(n) = 1 + \frac{1}{2} + \frac{1}{3} + \frac{1}{4} + \cdots + \frac{1}{n}$ is the Harmonic series.

Harmonic Series Approximation



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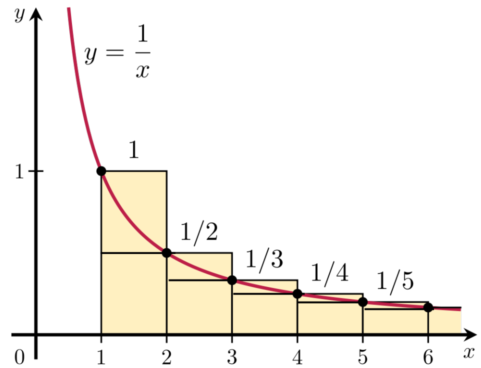

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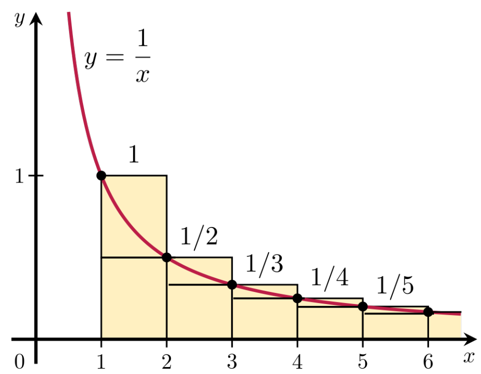

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Combining: $\ln(n+1) < H(n) < 1 + \ln(n)$.

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$\therefore\ H(n) \approx \ln n + \gamma$.

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$\therefore$ **Quicksort is indeed quick on the average!!**

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  - It is an in-place algorithm.
- **Improvement:** By choosing the base of the induction wisely.
  - The idea is to start the induction not always from 1.
  - Use, simple sorting techniques, like insertion sort or selection sort for small sequences.
  - **Note:** The efficiency of quicksort shows only for large sequences.
  - Define the base case for quicksort to be of size larger than 1 (10 to 20 is a good size).
  - Handle the base case by insertion sort or selection sort.

Introduction to Data Structures

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- They are the building blocks of computer algorithms.
- Design of an algorithm must be based on a thorough understanding of data structure techniques and costs.

Abstract Data Type (ADT)

- It is a useful notion in the study of data structures.
- Normally, when we write a program, we have to specify the data type (e.g., integers, reals, characters).
  - Also called primitive data structures.
  - Directly operated upon by the machine-level instructions.

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  Example:
  - **Frequent Operations:** Insertions and deletions.
  - **Condition:** First-in first-out (FIFO).
  - **Data Structure:** Queue.
- It is more convenient and more general to design algorithms for these operations without specifying the data type of the items.

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- If our needs matches the definition of an ADT, we use it.
- Make the algorithm-design process more modular.

Abstract Data Type: Definition

Definition

An abstract data type (ADT) is a mathematical model for data types, where a data type is defined by its behavior (semantics) from the point of view of a *user* of the data, specifically in terms of possible values, possible operations on data of this type, and the behavior of these operations.

In contrast a Data structures requires

- concrete representations of data, and
- are of the point of view of an *implementer* and not a *user*.

ADT Example: Integers

Integers are an ADT, defined by the

- Values: $\ldots, -2, -1, 0, 1, 2, \ldots$, and by the
- Operations: '$+$', '-', '$\cdot$', '$/$', '$<$', etc.
- Behavior:
  - Obeying various axioms (associativity and commutativity of addition etc.).
  - Preconditions on operations (cannot divide by zero).
  - Must be independent of how the integers are represented.
- Representation:
  - Typically represented in 2's complement.
  - Can also be binary-coded decimal or in 1' complement.
- User:
  - Abstracted from the concrete choice of representation.
  - Simply use it as data types.

Elementary Data Structures

- Sets are also fundamental to computer science.
- Dynamic Sets: Sets manipulated by algorithms can *grow*, *shrink*, or *change over time*.
- Algorithms may require several different types of operations to be performed on sets.
- Dictionary: A dynamic set that supports insertion, deletion, and membership testing.
- The best way to implement a dynamic set depends upon the operations that must be supported.

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- **Assumption:** All these operations take unit amount of time.

Keys and Satallite Data

Keys:

- An identifying field of the objects in a dynamic set.
- If all the keys are different, then we think of the dynamic set as being a set of key values.

Satellite Data:

- Data carried around in other object fields but are otherwise not part of the implementation.

Operations on a Dynamic Set

- Can be grouped into two categories:
  - **Queries:** Which simply return information about the set.
  - **Modifying Operations:** Which change the set.

Modifying Operations

$\text{INSERT}(S, x)$: Augments the set S with the element pointed to by x.

$\text{DELETE}(S, x)$: Given a pointer to an element x in the set S, removes x from S.

Note: These operations uses a pointer to x and not a key value.

Queries

$\textsc{Search}(S, k)$: Given a set S and a key value k, returns

- a pointer x to an element in S such that $key[x] = k$, or
- **nil** if no such element belongs to S.

$\textsc{Minimum}(S)$: Returns a pointer to the element with smallest key.

$\textsc{Maximum}(S)$: Returns a pointer to the element with largest key.

$\textsc{Successor}(S, x)$: Given an element x, returns

- a pointer to the next larger element in S, or
- **nil** if x is the maximum element.

$\textsc{Predecessor}(S, x)$: Given an element x, returns

- a pointer to the next smaller element in S, or
- **nil** if x is the minimum element.

ADT: Arrays

Arrays

- Row of elements of the same type.
- The size of an array is the number of elements in that array.
- The size must be fixed.
- $\therefore$ all the elements are of the same type.
- Thus amount of memory is known a priori.
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- Every element of an array can be accessed in constant time.
- **Drawbacks:**
  - Cannot be used to store elements of different types (or sizes).
  - The size of an array cannot be changed dynamically.

ADT: Records

Records

- Similar to arrays, except elements can be of different types.
- A record is thus a list of elements of different types.
- The exact combination of types is fixed.
- $\therefore$ the storage size of a record is known in advance.
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- A record is thus a list of elements of different types.
- The exact combination of types is fixed.
- $\therefore$ the storage size of a record is known in advance.
- Each element in a record can be accessed in constant time.
  - This is accomplished by keeping an array.
  - Element are then accessed by consulting the array.
  - The exact program that maintains the array is created automatically by the compiler.

Records: An Example

record example1
Begin
Int1 : integer;
Int2 : integer;
Ar1 : array[1 . . . 20] of integer;
Ar2 : array[1 . . . 20] of integer;
Ar3 : array[1 . . . 20] of integer;
Int3 : integer;
Int4 : integer;
Int5 : integer;
Int6 : integer;
Name1 : array[1 . . . 11] of character;
Name2 : array[1 . . . 12] of character;

End

- The array contains starting relative locations of all the elements.
- Thus 'Int6' starts at byte number 261 $(= 2{\cdot}4+3{\cdot}20{\cdot}4+3{\cdot}4+1)$
- Like arrays, the storage for a record is always consecutive.

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- **Drawback:** It is not possible to add elements dynamically.

Records in C

```
struct Record {
   int Int1;
   int Int2;
   int Ar1[20];
   int Ar2[20];
   int Ar3[20];
   int Int3;
   int Int4;
   int Int5;
   int Int6;
   char Name1[11];
   char Name2[12];
} Example1;
```

Records in C

```
struct Record {
   int Int1;
   int Int2;
   int Ar1[20];
   int Ar2[20];
   int Ar3[20];
   int Int3;
   int Int4;
   int Int5;
   int Int6;
   char Name1[11];
   char Name2[12];
} Example1;
```

sizeof(Example1)?

Books Consulted

1. Chapter 10 of *Introduction to Algorithms* by Thomas H Cormen, Charles E Leiserson, Ronald L Rivest, Clifford Stein.

Thank You for your kind attention!

Questions!!