CSCI 136: Data Structures and Advanced Programming

Lecture 27

Hash tables

Instructor: Kelly Shaw

Williams

Topics

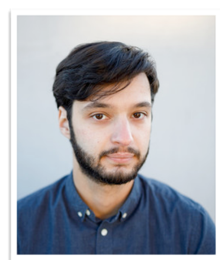
Hash tables

Hash functions

Your to-dos

1. Read **before Wed**: Bailey, Ch 16-16.2.
2. Lab 9 **(partner lab)**, **due Tuesday 11/29 by 10pm**.
3. Quiz, due Saturday evening.

Announcements



Computer Science Colloquium

Friday, November 18 @ 2:35pm in **Wege (TCL 123)**

Daniel Malinsky (Columbia)

Identifying Causal Determinants of Clinical Outcomes from Electronic Health Records Using Graphical Structure Learning: Challenges and Opportunities in Causal Discovery

Many goals within causal inference, including estimating average treatment effects and understanding path-specific mechanisms, depend on knowing the qualitative causal structure underlying a domain. In this work we apply methods for graphical causal discovery (specifically the FCI algorithm) to observational data in the form of electronic health records (EHR) from Johns Hopkins Hospital. Our goal is to understand the causal determinants of postoperative length of stay for patients undergoing cardiac surgery procedures, in order to inform possible interventions that support faster patient recovery. We discuss the challenges in applying causal discovery methods to electronic health records and opportunities for future work.

Hash tables

Dan's favorite data structure

Note about lab 9:

You should use the structure5 `Hashtable` implementation.

But if you want the extra challenge, implement your own!

Recall: arrays

An **array** is a data structure consisting of a **sequential collection of elements**, each identified by an **index**.

A	13	2	451	42	9	6	-4	8
	0	1	2	3	4	5	6	7

Performance guarantees:

1. **read** an element: **O(1)**
2. **write** an element: **O(1)**

Can we capture some of this for a more general structure?

Generalization: associative array

An **associative array** is a data structure consisting of a **sequential collection of elements**, each identified by a **key**. An associative array is a **map**.

A	13	2	451	42	9	6	-4	8
	Joe	Adam	Sue	Ed	Sam	Fay	Dan	Ted

Performance guarantees:

1. **read** an element: **O(1)?**
2. **write** an element: **O(1)?**

How can we make this happen?

What about MapTree?

It is already a map, which is good, but…

A	13	2	451	42	9	6	-4	8
	Joe	Adam	Sue	Ed	Sam	Fay	Dan	Ted

Performance guarantees:

1. **read** an element: **O(log n) (assuming balance)**
2. **write** an element: **O(log n) (assuming balance)**

Not fast enough!

Could we actually just use an array?

A	13	2	451	42	9	6	-4	8
	Joe	Adam	Sue	Ed	Sam	Fay	Dan	Ted

What do you think? What's the **obstacle**?

Need: function to map key to index

Suppose we have a **function**:

$$h(k) \rightarrow z$$

where k is a key of **arbitrary type** and $z \in \mathbb{Z}_0^+$,

then we could construct another function:

```
int index(K key) {
  return h(key) % A.length;
}
```

A	13	2	451	42	9	6	-4	8
	Joe	Adam	Sue	Ed	Sam	Fay	Dan	Ted

Hash function

A **hash function** is any function that can be used to map data of **arbitrary size** onto data of a **fixed size**.

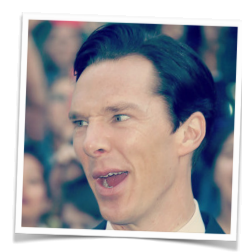
A	13	2	451	42	9	6	-4	8
	Joe	Adam	Sue	Ed	Sam	Fay	Dan	Ted

String of length 2.

String of length 3.

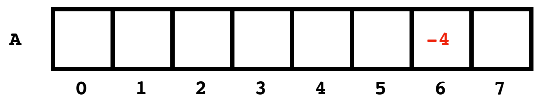
String of length 4.

Why not "`Benedict Cumberbatch`"?



Hash table

A **hash table** is a data structure that implements the **map** abstract data type. A hash table uses a **hash function** to compute an **index** into an array of **buckets**, from which the desired value can be found.



"Dan", -4

`index("Dan") → 6`

`A[index("Dan")] = -4`

Hash function

Hash functions must also provide the following guarantees:

Determinism: a given input value must always generate the same hash value.

Uniformity: maps the expected inputs as evenly as possible over its output range.

Equivalence: any two values that are considered equivalent should produce the same hash value.

Question

Is a function that **generates a random number** a **good hash function**?

No. Random numbers do tend to be uniform, but are not deterministic.

Activity

See if you can come up with a simple hash function for strings.

Determinism: a given input value must always generate the same hash value.

Uniformity: maps the expected inputs as evenly as possible over its output range.

Equivalence: any two values that are considered equivalent should produce the same hash value.

American Standard Code for Information Interchange (ASCII)

Dec	Hx	Oct	Char	Dec	Hx	Oct	Html	Chr	Dec	Hx	Oct	Html	Chr	Dec	Hx	Oct	Html	Chr
0	0	000	NUL (null)	32	20	040		Space	64	40	100	@	@	96	60	140	`	`
1	1	001	SOH (start of heading)	33	21	041	!	!	65	41	101	A	A	97	61	141	a	a
2	2	002	STX (start of text)	34	22	042	"	"	66	42	102	B	B	98	62	142	b	b
3	3	003	ETX (end of text)	35	23	043	#	#	67	43	103	C	C	99	63	143	c	c
4	4	004	EOT (end of transmission)	36	24	044	$	$	68	44	104	D	D	100	64	144	d	d
5	5	005	ENQ (enquiry)	37	25	045	%	%	69	45	105	E	E	101	65	145	e	e
6	6	006	ACK (acknowledge)	38	26	046	&	&	70	46	106	F	F	102	66	146	f	f
7	7	007	BEL (bell)	39	27	047	'	'	71	47	107	G	G	103	67	147	g	g
8	8	010	BS (backspace)	40	28	050	(	(	72	48	110	H	H	104	68	150	h	h
9	9	011	TAB (horizontal tab)	41	29	051	)	)	73	49	111	I	I	105	69	151	i	i
10	A	012	LF (NL line feed, new line)	42	2A	052	*	*	74	4A	112	J	J	106	6A	152	j	j
11	B	013	VT (vertical tab)	43	2B	053	+	+	75	4B	113	K	K	107	6B	153	k	k
12	C	014	FF (NP form feed, new page)	44	2C	054	,	,	76	4C	114	L	L	108	6C	154	l	l
13	D	015	CR (carriage return)	45	2D	055	-	-	77	4D	115	M	M	109	6D	155	m	m
14	E	016	SO (shift out)	46	2E	056	.	.	78	4E	116	N	N	110	6E	156	n	n
15	F	017	SI (shift in)	47	2F	057	/	/	79	4F	117	O	O	111	6F	157	o	o
16	10	020	DLE (data link escape)	48	30	060	0	0	80	50	120	P	P	112	70	160	p	p
17	11	021	DC1 (device control 1)	49	31	061	1	1	81	51	121	Q	Q	113	71	161	q	q
18	12	022	DC2 (device control 2)	50	32	062	2	2	82	52	122	R	R	114	72	162	r	r
19	13	023	DC3 (device control 3)	51	33	063	3	3	83	53	123	S	S	115	73	163	s	s
20	14	024	DC4 (device control 4)	52	34	064	4	4	84	54	124	T	T	116	74	164	t	t
21	15	025	NAK (negative acknowledge)	53	35	065	5	5	85	55	125	U	U	117	75	165	u	u
22	16	026	SYN (synchronous idle)	54	36	066	6	6	86	56	126	V	V	118	76	166	v	v
23	17	027	ETB (end of trans. block)	55	37	067	7	7	87	57	127	W	W	119	77	167	w	w
24	18	030	CAN (cancel)	56	38	070	8	8	88	58	130	X	X	120	78	170	x	x
25	19	031	EM (end of medium)	57	39	071	9	9	89	59	131	Y	Y	121	79	171	y	y
26	1A	032	SUB (substitute)	58	3A	072	:	:	90	5A	132	Z	Z	122	7A	172	z	z
27	1B	033	ESC (escape)	59	3B	073	;	;	91	5B	133	[	[	123	7B	173	{	{
28	1C	034	FS (file separator)	60	3C	074	<	<	92	5C	134	\	\	124	7C	174			|
29	1D	035	GS (group separator)	61	3D	075	=	=	93	5D	135	]	]	125	7D	175	}	}
30	1E	036	RS (record separator)	62	3E	076	>	>	94	5E	136	^	^	126	7E	176	~	~
31	1F	037	US (unit separator)	63	3F	077	?	?	95	5F	137	_	_	127	7F	177	&#127;	DEL

Source: www.LookupTables.com

(code)

Hash codes

Hashing is so important that **every `Object` in Java** has a built-in hash function.

hashCode

`public int hashCode()`

Returns a hash code value for the object. This method is supported for the benefit of hash tables such as those provided by `HashMap`.

The general contract of `hashCode` is:

- Whenever it is invoked on the same object more than once during an execution of a Java application, the `hashCode` method must consistently return the same integer, provided no information used in `equals` comparisons on the object is modified. This integer need not remain consistent from one execution of an application to another execution of the same application.
- If two objects are equal according to the `equals(Object)` method, then calling the `hashCode` method on each of the two objects must produce the same integer result.
- It is *not* required that if two objects are unequal according to the `equals(java.lang.Object)` method, then calling the `hashCode` method on each of the two objects must produce distinct integer results. However, the programmer should be aware that producing distinct integer results for unequal objects may improve the performance of hash tables.

As much as is reasonably practical, the hashCode method defined by class `Object` does return distinct integers for distinct objects. (This is typically implemented by converting the internal address of the object into an integer, but this implementation technique is not required by the Java™ programming language.)

Returns:

a hash code value for this object.

See Also:

`equals(java.lang.Object)`, `System.identityHashCode(java.lang.Object)`

Hash codes

Good hash functions are already provided for **primitives**.

Provide one for your own class by overriding **`hashCode`**.

hashCode

`public int hashCode()`

Returns a hash code value for the object. This method is supported for the benefit of hash tables such as those provided by `HashMap`.

The general contract of `hashCode` is:

- Whenever it is invoked on the same object more than once during an execution of a Java application, the `hashCode` method must consistently return the same integer, provided no information used in `equals` comparisons on the object is modified. This integer need not remain consistent from one execution of an application to another execution of the same application.
- If two objects are equal according to the `equals(Object)` method, then calling the `hashCode` method on each of the two objects must produce the same integer result.
- It is *not* required that if two objects are unequal according to the `equals(java.lang.Object)` method, then calling the `hashCode` method on each of the two objects must produce distinct integer results. However, the programmer should be aware that producing distinct integer results for unequal objects may improve the performance of hash tables.

As much as is reasonably practical, the hashCode method defined by class `Object` does return distinct integers for distinct objects. (This is typically implemented by converting the internal address of the object into an integer, but this implementation technique is not required by the Java™ programming language.)

Returns:

a hash code value for this object.

See Also:

`equals(java.lang.Object)`, `System.identityHashCode(java.lang.Object)`

Is our simple hash function actually good?

Recap & Next Class

Today:

Hash tables

Hash functions

Next class:

Collisions

Graphs