15-122: Principles of Imperative Computation — Spring 2024

Lab 08: Hash This! — Tuesday March 12th

Collaboration: In lab, we encourage collaboration and discussion as you work through the problems. These activities, like recitation, are meant to get you to review what we've learned, look at problems from a different perspective and allow you to ask questions about topics you don't understand. We encourage discussing problems with other students in this lab!

Setup:
Download the lab handout and code from the course website https://cs.cmu.edu/ 15122/handouts/code, and move it to your private directory in your unix.qatar.cmu.edu machine. Following that create a directory, move the handout to it, and unzip the handout file by executing the following commands:

```
% mkdir lab_08
% mv 08-handout.tgz lab_08
% cd lab_08
% tar -xvf 08-handout.tgz
```

Submission:
To submit, create a tar file by executing the command below and submit it to autolab, under the lab name:

```
% tar cfzv handin.tgz my-hash-mul32.c0 my-hash-lcg.c0 hash-profs.c0
```

Finding collisions in hash functions

Recall that a hash function $h(k)$ takes a key k as its argument and returns some integer, a *hash value*; we can then use $\text{abs}(h(k)\%m)$ as an index into our hash table. In this lab you will be examining various hash functions and exploiting their inefficiencies to make them collide.

It will be convenient to denote a string of length n (for $n > 0$) as $s_0 s_1 s_2 ... s_{n-2} s_{n-1}$, where s_i is the ASCII value of character i in string s. (A partial ASCII table is given to the right.) We define four hash functions as follows:

`hash_add`: $h(s) = s_0 + s_1 + s_2 + \cdots + s_{n-2} + s_{n-1}$

`hash_mul32`:

$$h(s) = (\ldots((s_0 \times 32 + s_1) \times 32 + s_2) \times 32 \cdots + s_{n-2}) \times 32 + s_{n-1}$$

`hash_mul31`:

$$h(s) = (\ldots((s_0 \times 31 + s_1) \times 31 + s_2) \times 31 \cdots + s_{n-2}) \times 31 + s_{n-1}$$

`hash_lcg`:

$$h(s) = f(f(\ldots f(f(f(s_0) + s_1) + s_2) \cdots + s_{n-2}) + s_{n-1})$$

where $f(x) = 1664525 \times x + 1013904223$

(1.a) What does each of these functions reduce to when n=1?

Partial ASCII Table

32	20	␣	64	40	@	96	60	‘
33	21	!	65	41	A	97	61	a
34	22	"	66	42	B	98	62	b
35	23	#	67	43	C	99	63	c
36	24	$	68	44	D	100	64	d
37	25	%	69	45	E	101	65	e
38	26	&	70	46	F	102	66	f
39	27	’	71	47	G	103	67	g
40	28	(	72	48	H	104	68	h
41	29	)	73	49	I	105	69	i
42	2A	*	74	4A	J	106	6A	j
43	2B	+	75	4B	K	107	6B	k
44	2C	,	76	4C	L	108	6C	l
45	2D	-	77	4D	M	109	6D	m
46	2E	.	78	4E	N	110	6E	n
47	2F	/	79	4F	O	111	6F	o
48	30	0	80	50	P	112	70	p
49	31	1	81	51	Q	113	71	q
50	32	2	82	52	R	114	72	r
51	33	3	83	53	S	115	73	s
52	34	4	84	54	T	116	74	t
53	35	5	85	55	U	117	75	u
54	36	6	86	56	V	118	76	v
55	37	7	87	57	W	119	77	w
56	38	8	88	58	X	120	78	x
57	39	9	89	59	Y	121	79	y
58	3A	:	90	5A	Z	122	7A	z
59	3B	;	91	5B	[	123	7B	{
60	3C	<	92	5C	\	124	7C	|
61	3D	=	93	5D	]	125	7D	}
62	3E	>	94	5E	^	126	7E	∼
63	3F	?	95	5F	_			

These four hash functions have been implemented for you and can be run from the command line like this, for example:

```
% hash_add
Enter a string to hash: bar
   hash value = 309
   hashes to index 309 in a table of size 1024
Another? (empty line quits):
```

Note that the command line hashing tool also reports where the element with the given key will hash to given a table size of 1024. This is important because hash tables have a limited size, so we want to minimize collisions within said size.

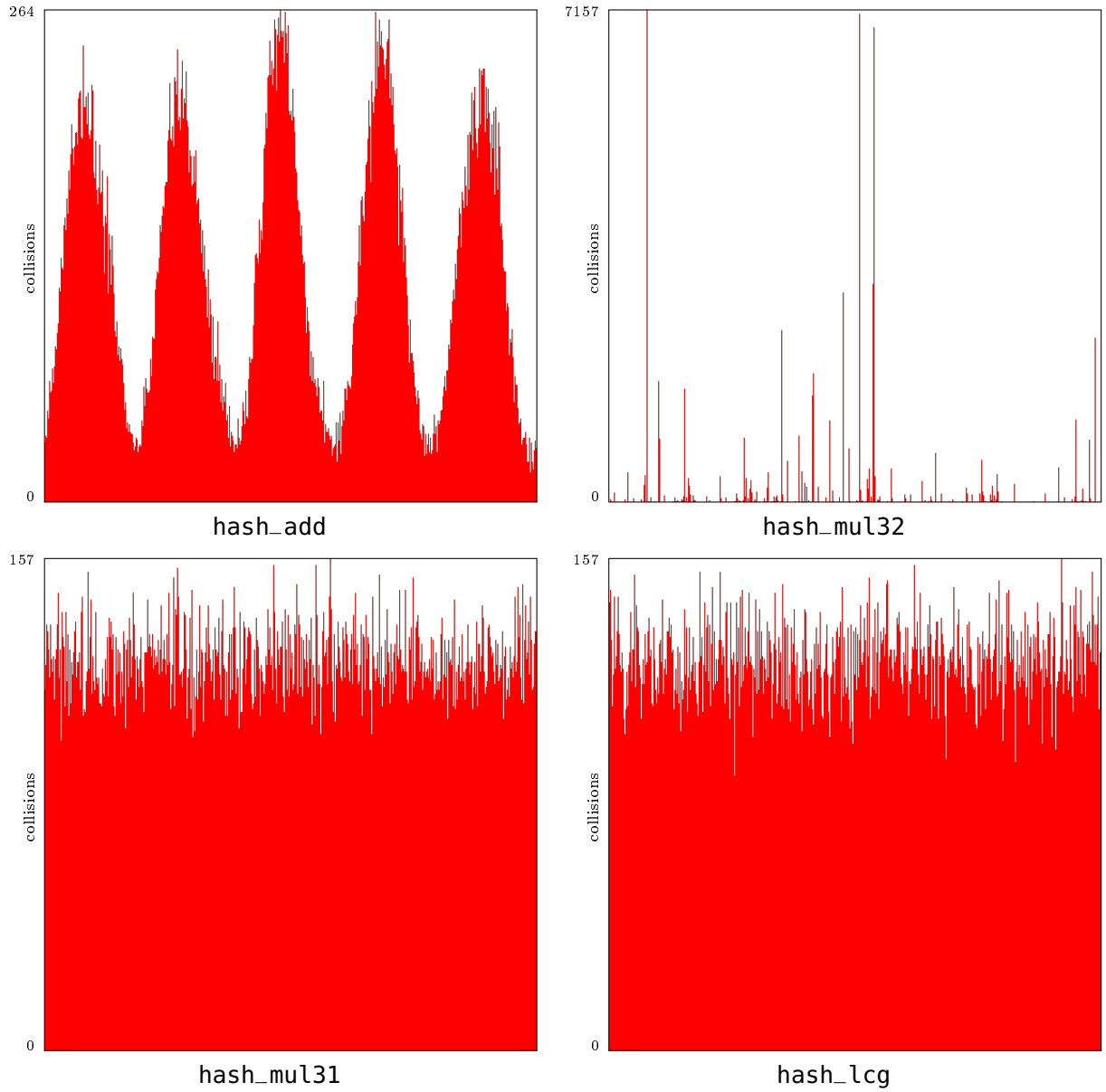
The first exercise requires you to mathematically reverse-engineer one of the simpler hash functions:

(1.b) Find three or more strings, each string containing three or more characters, that would always collide because they have the same hash value using `hash_add`.

1.5pt

Now, let's work through a more complicated real-world example: hashing an entire dictionary. We would like to know which hashing function would be the best to hash the 64,000 word Scrabble dictionary. We define a hashing function to be "better" based on how efficiently it spreads out the words over the buckets. Obviously, this depends on the size of our hash table: if we have a smaller hash table, there will naturally be more collisions. That's why we can use a visualizer (implemented for you in file `visualizer.c0`) to see how many words hash to each bucket for a given hash function.

Here is a graphical visualization of each of the four hash functions on the Scrabble dictionary and a table of size 512. The vertical lines show how many values hashed to that index in the table.



(1.c) Examine carefully these visualizations and comment on how good each hash function is.

Your turn to do some coding!

(1.d) Implement your own version of `hash_mul32` in file `my-hash-mul32.c0` so that the function `hash_string(s)` returns an integer representing the hash value for `s` using the formula given on the previous page. The **<string>** library may be helpful in this. You can use `coin` to test your implementation on some input strings, and compare the results by running `hash_mul32` on the same strings.

To visualize the collisions, compile your code and run it with the following command:

```
% cc0 -o my-hash-mul32 my-hash-mul32.c0 hash-dictionary.c0 visualizer.c0
% ./my-hash-mul32 -o my-mul32.png
% display my-mul32.png
```

This will output a graphical visualization of your hash function on the dictionary for a table of size 512, with the vertical lines showing how many values hashed to that index in the table. Compare your visualization with the one given earlier for `hash_mul32`. If you are ssh'ing remember to ssh with `-Y` or `-X`! You can run your program with the `-n` flag followed by a different table size if you like.

(1.e) Now, similarly implement `hash_lcg` in `my-hash-lcg.c0`, and compile it for the dictionary:

```
% cc0 -o my-hash-lcg my-hash-lcg.c0 hash-dictionary.c0 visualizer.c0
% ./my-hash-lcg -o my-lcg.png
% display my-lcg.png
```

3pt Compare this to what you got with our visualization for `hash_lcg`.

Hashing faculty

In file `profs.txt`, there is a list of CS faculty info, which we will parse for you into the following structs. We would like to hash such structs into a hash table (some fields may be blank):

```
typedef struct prof_header prof;
struct prof_header {
  string name;
  string title;
  string office;
  string email;
  int area_code;    // 0 if no phone number
  int phone;        // 0 if no phone number
};
```

(2.a) In file `hash-profs.c0`, implement the function `hash_prof(prof* p)` that returns a hash value for a `prof_header` struct. Your implementation should use the function `hash_string` you wrote earlier and hash at least two **`string`** fields from this struct. Then, compile them against both your `hash_mul32` and `hash_lcg` and compare the resulting visualizations:

```
% cc0 -o profs-mul32 my-hash-mul32.c0 hash-profs.c0 visualizer.c0
% ./profs-mul32 -o profs-mul32.png

% cc0 -o profs-lcg my-hash-lcg.c0 hash-profs.c0 visualizer.c0
% ./profs-lcg -o profs-lcg.png
```

Compare your visualizations with those of your neighbors, who probably defined `hash_prof` differently from you. Try and understand what makes a better hashing function! **Hint:** try lowering the bucket size by passing the additional flag `-n <num buckets>` to your executables as there are way less faculty than words in the Scrabble dictionary.

For full credit, the maximum bucket size on the default table of size 512 should be 12 or lower when compiled using `hash_lcg`, and the visualizations should indicate a good hash function.

4pt