Developing data structures for JavaScript

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Why and how to implement efficient data structures to use with node.js or in the browser?

Who am I?

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What's a data structure?

«Web development is not real development and is henceforth easier.»

Someone wrong on the Internet.

«Web development is trivial and web developers don't need fancy data structures or any solid knowledge in algorithmics.»

Someone also wrong (and pedant) on the Internet.

Don't we already have fully satisfying data structures in JavaScript?

- `Array` ➡ lists of things
- `Object` ➡ key-value associations
- `Map` and `Set` with ES6

- **Why would we want other data structures in JavaScript?**

- **Convenience and bookkeeping**

A MultiSet

```
// How about changing this:
const counts = {};

for (const item in something) {
  if (!(item in counts))
    counts[item] = 0;

  counts[item]++;
}
```

```
// Into this:
const counts = new MultiSet();

for (const item in something)
  counts.add(item);
```

- **Complex structures: a Graph**

Sure, you can "implement" graphs using only `Array` and `Object`™.

But:

- Lots of bookkeeping (multi-way indexation)
- Wouldn't it be nice to have a legible interface?

Examples taken from the graphology library:

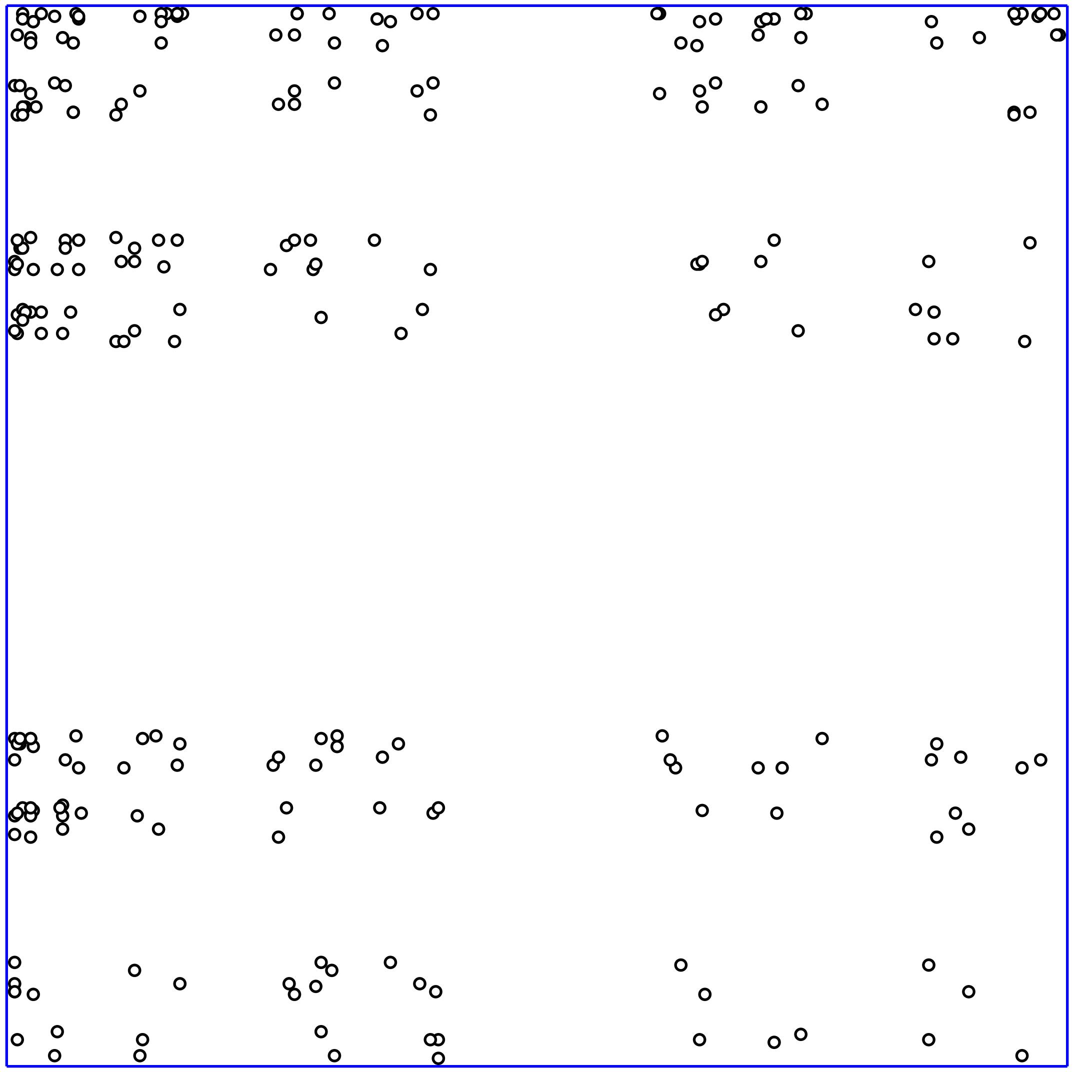
```
const graph = new Graph();

// Finding specific neighbors
const neighbors = graph.outNeighbors(node);

// Iterating over a node's edges
graph.forEachEdge(node, (edge, attributes) => {
  console.log(attributes.weight);
});
```

- **Sometimes Arrays and Objects are not enough**

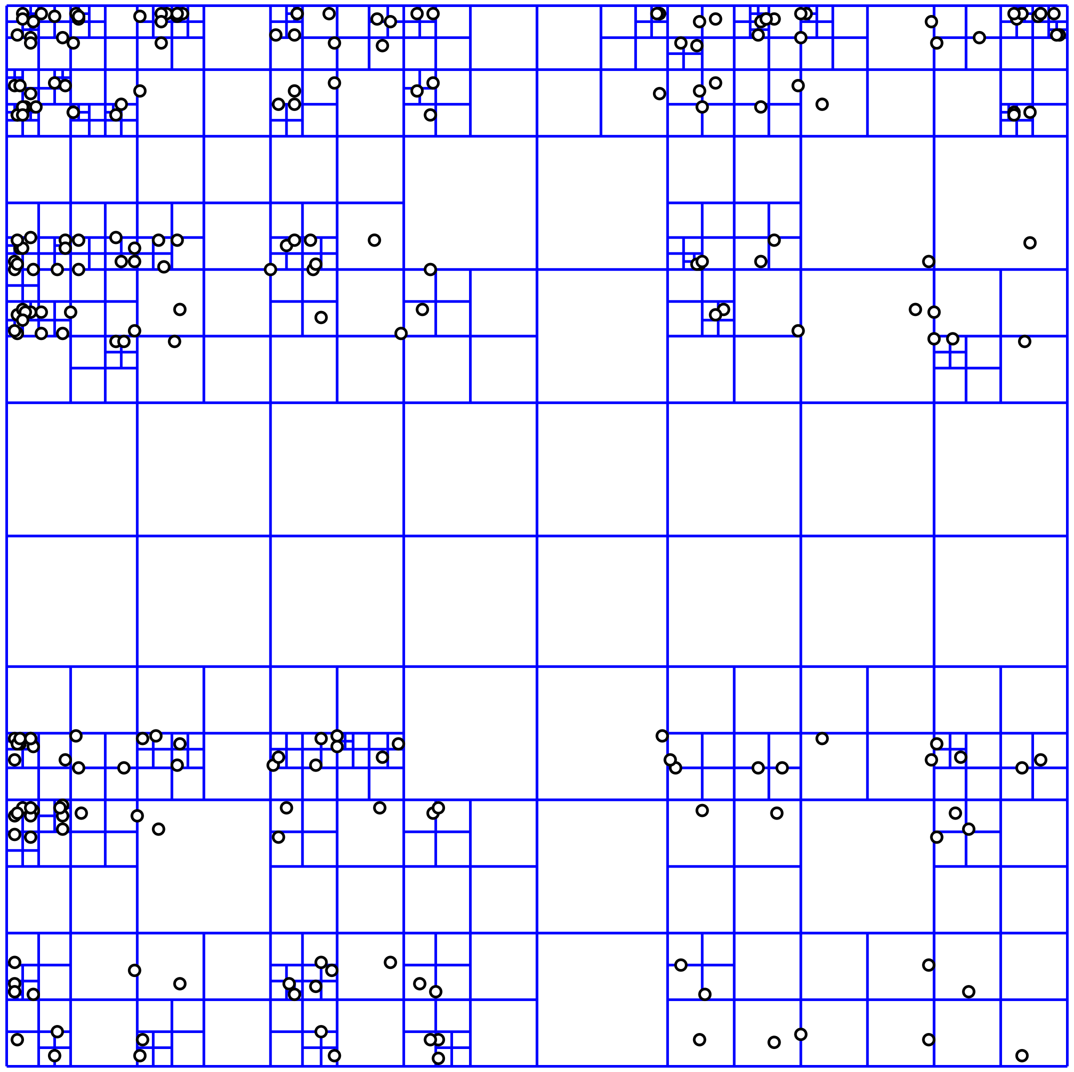
- **More than just tacky website candy**

- We process data on the client nowadays.
- Node.js became a thing.
- Some algorithms cannot be efficiently implemented without custom data structures (Dijkstra or Inverted Index for full text search etc.).

- **The QuadTree**



- **The QuadTree**



- **What are the challenges?**

- **Interpreted languages are far from the metal**

- **No control over memory layout**
- **No control over garbage collection**

- JIT & optimizing engines such as Gecko / V8

Benchmarking code accurately is **not** easy.

It does not mean we cannot be **clever** about it.

- **Implementation tips**

- **Time & memory performance**

Minimizing lookups

"Hashmap" lookups are costly.

```
// You made 2 lookups
Graph.prototype.getNodeAttribute = function(node, data) {
  if (this._nodes.has(node))
    throw Error(...);

  const data = this._nodes.get(node);

  return data[name];
};
```

```javascript
// You made only one
Graph.prototype.getNodeAttribute = function(node, data) {
  const data = this._nodes.get(node);

  if (typeof data === 'undefined')
    throw Error(...);

  return data[name];
};
```

```
# Result, 100k items
--------------------
Two lookups: 31.275ms
One lookup:  15.762ms
```

The engine is clever. But not *that* clever. (It improves frequently, though...)

The «*let's code badly, the engine will clean up my mess*» approach will not work.

- **Creating objects is costly**

  - Avoid allocating objects.
  - Avoid /(?:re-)?creating/ regexes.
  - Avoid nesting functions whenever possible.

```javascript
// BAD!
const test = x => /regex/.test(x);

// GOOD!
const REGEX = /regex/;
const test = x => REGEX.test(x);

// BAAAAAD!
function(array) {
  array.forEach(subarray => {

    // You just created one function per subarray!
    subarray.forEach(x => console.log(x));
  });
}
```

- **Mixing types is bad**

```
// Why do you do that?
// If you are this kind of person, can we meet?
// I really want to understand.
const array = [1, 'two', '3', /four/, {five: new Date()}];
```

- **The poor man's malloc**

- Byte arrays are fan-ta-stic.
- Byte arrays are light.
- You can simulate typed memory allocation: `Uint8Array`, `Float32Array` etc.

- **Implement your own pointer system!**

And have your very own "C in JavaScript"™.

```
A linked list (with pointers):
------------------------------
head -> (a) -> (b) -> (c) -> ø
```

```
// Using object references as pointers
function LinkedListNode(value) {
  this.next = null;
  this.value = value;
}
// Changing a pointer
node.next = otherNode;
```

```
A linked list (rolling our own pointers):
-----------------------------------------
head      = 0
values    = [a, b, c]
next      = [1, 2, 0]
```

```
// Using byte arrays (capacity is fixed)
function LinkedList(capacity) {
  this.head = 0;
  this.next = new Uint16Array(capacity);
  this.values = new Array(capacity);
}
// Changing a pointer;
this.next[nodeIndex] = otherNodeIndex;
```

- **Let's build a most efficient LRU Cache!**

- An object with maximum number of keys to save up some RAM.
- If we add a new key and we are full, we drop the **L**east **R**ecently **U**sed one.
- Useful to implement caches & memoization.

```
A ~doubly~ linked list:
-----------------------
head     = 0
tail     = 2
next     = [1, 2, 0]
prev     = [0, 1, 2]

Same as (with pointers):
------------------------
head -> (a) <-> (b) <-> (c) <- tail

A map to pointers & values:
---------------------------
items  = {a: 0, b: 1, c: 2}
values = [a, b, c]
```

name	set	get1	update	get2	evict
mnemonist-object	15314	69444	35026	68966	7949
tiny-lru	6530	46296	37244	42017	5961
lru-fast	5979	36832	32626	40900	5929
mnemonist-map	6272	15785	10923	16077	3738
lru	3927	5454	5001	5366	2827
simple-lru-cache	3393	3855	3701	3899	2496
hyperlru-object	3515	3953	4044	4102	2495
js-lru	3813	10010	9246	10309	1843

Bench here - I masked libraries which are not LRU per se.

- **Function calls are costly**

Everything is costly. Life is harsh.

This means that rolling your own stack will always beat recursion.

```javascript
// Recursive version - "easy"
function recurse(node, key) {
  if (key < node.value) {
    if (node.left)
      return recurse(node.left, key);

    return false;
  }
  else if (key > node.value) {
    if (node.right)
      return recurse(node.right, key);

    return false;
  }

  return true;
}
```

```javascript
// Iterative version - more alien but faster, mileage may vary
function iterative(root, key) {
  const stack = [root];
  while (stack.length) {
    const node = stack.pop();
    if (key < node.value) {
      if (node.left)
        stack.push(node.left);
      else
        break;
    }
    else if (key > node.value) {
      if (node.right)
        stack.push(node.right);
      else
        break;
    }
    return true;
  }
  return false;
}
```

- **What about wasm etc. ?**

Lots of shiny options:

1. asm.js
2. WebAssembly
3. Native code binding in Node.js

Communication between those and JavaScript has a cost that negates the benefit.

This is only viable if you have long running code or don't need the bridge between the layer and JavaScript.

- **Parting words**

- **Yes, optimizing JavaScript is hard.**

- **But it does not mean we cannot do it.**

- **Most tips are applicable to every high-level languages.**

- **But JavaScript has its very own kinks**

The `ByteArray` tips absolutely don't work in python.

It's even slower if you use `numpy` arrays. (you need to go full native).

- **The gist**

To be efficient your code must be **statically interpretable**.

If you do that:

1. The engine will have **no hard decisions** to make
2. And will safely choose the most aggressive optimization paths

- **Rephrased**

Optimizing JavaScript = squinting a little and **pretending** really hard that:

1. The language has static typing.
2. That the language is low-level.

- **Associative arrays are the next frontier**

For now, there is no way to beat JavaScript's objects and maps when doing key-value association.

Yet...

- So implement away!

References

Examples were taken from the following libraries:

- mnemonist: *yomguithereal.github.io/mnemonist*
- graphology: *graphology.github.io*
- sigma.js: *sigmajs.org*

Thanks!