What does it take to create with domain-appropriate tools?

Reflections on implementing the “Id” system

Joel Jakubovic

a University of Kent, Canterbury

Abstract There is a One-Size-Fits-All quality to languages, APIs and even programming itself. Whether you’re making a mobile game or a scientific simulation, you will be using a text-based language with similar devices for structuring your code. This is a source of artificial difficulty in creating, understanding, and modifying software systems. No matter the domain, the author’s design needs encoding into a form that does not resemble it.

This paper describes a vision where software can be built in a programming environment that is closer to the domain of the software itself. By doing so, users of the system can use familiar abstractions and tools for adapting it. A step towards this vision is presented: a Web version of a minimal OOP system, developed as an executable version of the diagrams of its design, in a substrate meant to facilitate this. The experience of creating such a substrate is analysed, and I suggest deficiencies in programming environments that stand in the way of making this practice commonplace, as well as ways to fill in these gaps.

ACM CCS 2012

- **Software and its engineering → Domain specific languages; Visual languages;**

The Art, Science, and Engineering of Programming

Perspective The Art of Programming

Area of Submission Domain-specific programming, visual programming, self-sustaining systems

1 Introduction

As someone who can code, I have already passed the first and most important hurdle for making full use of the potential of my computer. However, even in this supposedly empowered state, I am still far away from feeling the relationship between myself and software as between artisan and material, free to shape it into any form with effort proportional to complexity.

One would have thought that software-creation acts like hypothetical super-intelligent Artificial Intelligence (AI). That is: even though we start from a primitive base in the 50s (or even today), there would surely be a recursive process of self-improvement, building better software-creation tools with the existing ones, until an "expressivity singularity" where software becomes a workable material as described.

However, this didn't happen. Or at least, it is happening glacially slowly. The brute fact is that whenever you want to create software, you go to a text editor and figure out how to translate your design into that. The text editors, being software, were written with the help of previous text editors, and so on. It's undeniable that text editors have improved, even if you think it peaked with Emacs. We just don't seem able to go beyond them where it matters, such as visual domains ill-fitted to monospaced ASCII.

Amdahl's Law generalises the following idea: even when you spend hours of effort doubling the performance of a component used 1% of the time, your reward is a system overall improved by a mere 0.5%. Now, text coding is certainly ubiquitous, the 99% case in programming. A small improvement to text editing, if adopted by everyone, certainly does have a massive *intermediate* effect—but this only *matters* to the extent that text was helping us in the first place. If my goal is to draw or animate pictures, or create a digital synth from a frequency spectrogram, then giving me the ability to auto-indent my SVG markup is rather underwhelming as a productivity increase, as it doesn't target the core of the enterprise that makes it so hard.

As a programmer, I often feel stuck in a box I know I can never escape from: that box is the text editor, a fixed conduit through which all *fundamental* changes to my program must pass. It's not a part of the system I am building, so I can't even make use of features of the thing I'm developing, to make its own development easier.

Surely the trick is to *use* coding to build something *better than it*. And then use that, to build something even better. But there is an enormous breadth and depth of philosophies here, along with all sorts of concrete systems that failed to catch on. Even worse than this, is that in my very *language* here I am making the same mistake as the text editor—speaking in unqualified terms of "better" and "worse" as if there really is a One-Size-Fits-All solution to software creation!

Of course what we *really* want is the ability for people to create *in the way that they think is best*[1] in their particular context—to equip them to feasibly create the

[1] To be clear: if someone *wants* to type out pictures in ASCII, let them—whether they do it for a challenge, or even if they find that more natural for themselves. But equally, if I want to do it another way, I should have that affordance.

tools that suit them for the thing they want to make. And second-order tools that suit them for making the first-order tools, and so on. It would do no good to replace text-imperialism with anything-*else*-imperialism, which is one interpretation of calls for alternatives.

This dream goes beyond the familiar sense of what constitutes a "craft", as far as a strong melding of tool and material. Parallels can be drawn with industrialisation and a strong division of labour: the community as a whole produces its higher-order tools, but currently no single person can have the same autonomy. A (future) software craft could be expected to give this power to *individuals*, instead of the community alone. Whenever there are many small specialities (e.g. languages, tools, or subject areas) each serving many clients, the One-Size-Fits-All style is the best one can hope for. Adaptation to individual preferences and idiosyncrasies is only feasible when those individuals can do it themselves.

What we need is some system that not only lets us create software in a way that is "close to the problem domain" as decided by the user-developer, but also can augment or change itself to adapt to a different "way of creating". Existing systems seem to only have one of these properties without the other: Smalltalk and LISP try to minimise arbitrary commitments of language *semantics* to this end, but their being textual languages is a fairly tough commitment to break out of. And it is not so hard to make a specific, *hard-baked* visual or alternative programming tool—but it is hard to make it re-programmable *without* having to go back to *its* textual source code.

All these considerations attract me to the design of a particular system called "Id", as a potential way out of this mess [PW06]. True, it is a programmer's artefact, but it is still representative of what any normal person has to do, insofar as:

a) Wanting to create a piece of software (for whatever reason)
b) Having in mind a natural way to represent it as it's being built.

What follows in this paper is an account of how I went about building Id, atop a preliminary "box" substrate. Section~2 gives an overview of Id. Section~3 discusses the work involved in obtaining said domain-appropriate substrate, and Section~4 continues with an interpretation of the labour costs of doing this. In Section~5, we return to the Id system and its role in supporting flexible software. Section~6 addresses the question in the title, and concludes with next steps for the project.

2 The Id system

When I first read the paper "Open, Reusable Object Models" [PW06], I was hooked on its idea of a small but expressive starting system that could be self-improved into anything. It describes a late-bound,[2] Smalltalk-style[3] objects and messaging environment that the authors call "Id".

[2] Fewer commitments; more things determined by runtime conditions
[3] OOP with more emphasis on object instances and messaging, as in a distributed system; less emphasis on class hierarchies implementing traditional data structures

An Id *object* is a block of state which can change as a result of messages received by it. Messaging (analogous to *method invocation* in mainstream OOP) works as follows:

- A message is sent by first *bind*-ing its name to its *implementation*: specific code, which is then run in the context of the receiver R.
- This "bind" step is accomplished by sending a further message; this time, to the receiver's *vtable* $V(R)$. A vtable is another object that maps "message name" to "implementation code"—it's analogous to a "class" in mainstream OOP.
- This initial "bind" message triggers a similar "bind" to *its* vtable $V(V(R))$, and so on: recursing up the vtable-chain, and terminating at a base case.
- The higher levels of the vtable-chain mean that different kinds of vtables can be supported,[4] each implementing the "bind" operation in its own way.

Inkeeping with its aims of minimality and self-describability, Id as a whole is "bootstrapped" into existence by its initialisation code. Each step of this code makes use of any parts of the system set up by the previous steps.

The paper itself consists of mostly prose, several code listings, and full C sources for a sample implementation at the end. It also provides several diagrams. But to understand it, I repeatedly found myself drawing *extra* diagrams. For example, the first acts of the running system boil down to initialising the three or so objects. This consists of allocating memory, interpreting it as a C struct and then filling in fields in a mundane manner. I had great difficulty following the specifics in my head, but when I drew tables in the style of their diagrams I readily saw what what going on. I personally would have preferred these to have been in the paper in the first place, but I am not necessarily representative of those who read it.[5]

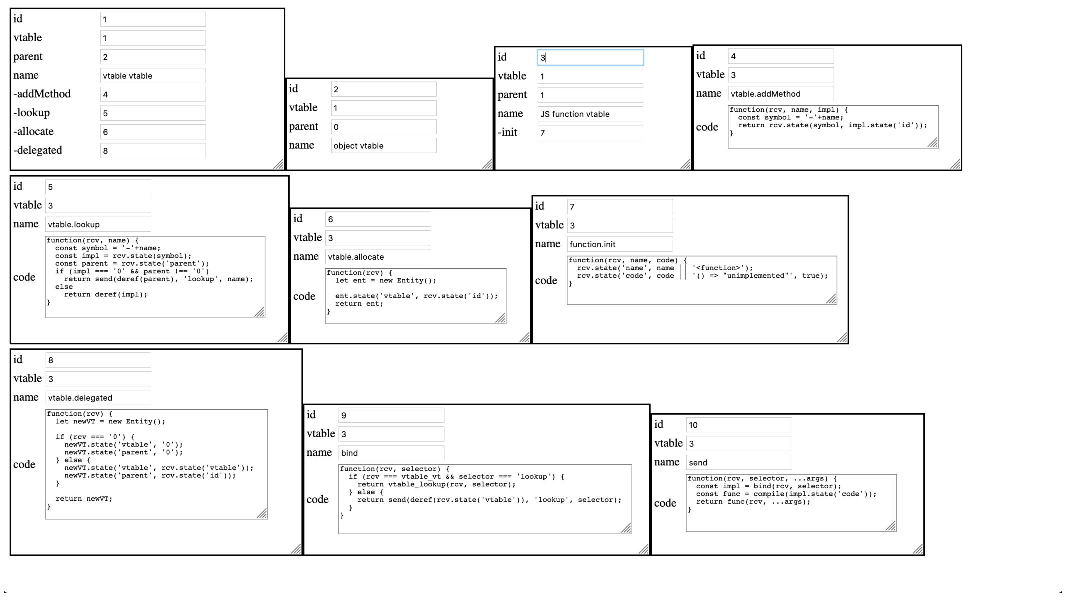
At any rate, in order to solidify my understanding, there was no better way than to run the thing and explore it. And yet, having already "de-compiled" English text and C source code into object diagrams, it is a shame to have to compile it all back to struct member assignments. Worse, the reference system does not even have text I/O when it is run, let alone some sort of GUI.[6] Faced with the necessity of adding *some* UI, it seemed a waste of effort to end up with a system that must be continually polled for its current state at a terminal prompt.

If I naturally think of this system as 2D tables, why can't that be how the running system looks? I do not have to keep polling my eyes for what state my diagrams are in. But further than that—why can't the system be *built* out of tables in the first place? Shouldn't this be the main takeaway from the amount of time we spend prototyping, explaining and designing software as diagrams on paper? Why must the "natural representation" be restricted to the finished product?

Thus was my natural representation decided. My first attempt to make it a reality was a partial success: a webpage made of HTML tables, evolved via JavaScript (JS).

[4] As well as different kinds of "kinds of vtables", and so on.
[5] Besides that, the One-Size-Fits-All approach is perhaps unavoidable for static print media.
[6] That is, the (un)intended user interface for Id ends up being a C debugger!

2.1 Id as HTML tables



id	1
vtable	1
parent	2
name	vtable vtable
-addMethod	4
-lookup	5
-allocate	6
-delegated	8

id	2
vtable	1
parent	0
name	object vtable

id	3
vtable	1
parent	1
name	JS function vtable
-init	7

id	4
vtable	3
name	vtable.addMethod

code
```
function(rcv, name, impl) {
  const symbol = '-'+name;
  return rcv.state(symbol, impl.state('id'));
}
```

id	5
vtable	3
name	vtable.lookup

code
```
function(rcv, name) {
  const symbol = '-'+name;
  const impl = rcv.state(symbol);
  const parent = rcv.state('parent');
  if (impl === '0' && parent !== '0')
    return send(deref(parent), 'lookup', name);
  else
    return deref(impl);
}
```

id	6
vtable	3
name	vtable.allocate

code
```
function(rcv) {
  let ent = new Entity();

  ent.state('vtable', rcv.state('id'));
  return ent;
}
```

id	7
vtable	3
name	function.init

code
```
function(rcv, name, code) {
  rcv.state('name', name || '<function>');
  rcv.state('code', code || '() => "unimplemented"', true);
}
```

id	8
vtable	3
name	vtable.delegated

code
```
function(rcv) {
  let newVT = new Entity();

  if (rcv === '0') {
    newVT.state('vtable', '0');
    newVT.state('parent', '0');
  } else {
    newVT.state('vtable', rcv.state('vtable'));
    newVT.state('parent', rcv.state('id'));
  }

  return newVT;
}
```

id	9
vtable	3
name	bind

code
```
function(rcv, selector) {
  if (rcv === vtable_vt && selector === 'lookup') {
    return vtable_lookup(rcv, selector);
  } else {
    return send(deref(rcv.state('vtable')), 'lookup', selector);
  }
}
```

id	10
vtable	3
name	send

code
```
function(rcv, selector, ...args) {
  const impl = bind(rcv, selector);
  const func = compile(impl.state('code'));
  return func(rcv, ...args);
}
```

Figure 1 Id/HTML: Obj-dicts are rendered as resizable tables, which reference each other through numerical IDs.

To emphasise the tendency of Id objects to be visualised as key-value mappings, I will refer to them as *obj-dicts*. Figure 1 shows the Id/HTML implementation [Jak18], in which they take the form of HTML tables.

Here, I was grateful for the browser's management of graphical layout, resizable text fields, and keeping the DOM tree synchronised with what one sees. This last property enabled me to make the decision to *directly* encode much of the system state in the DOM, achieving basic liveness ("The thing on the screen is the actual thing") for the keys and values of obj-dicts.

I used a two-column <table> within a <div> for each obj-dict (matching the diagrams) and gave the rows CSS class names matching the keys (for easy lookup). Sending messages relied on the JS console, but existing values in text boxes (such as method implementations) could be edited directly.

This choice of ordinary HTML as a substrate, however, proved rather two-edged. The browser requires many features to do its job of rendering complex web pages. And sadly, as its client, I could only make use of those capabilities which the W3C had decided, at the time of authorship, were worth the effort exposing in JavaScript. For anything else, the browser is a black box, and this was very frustrating in the following case.

2.1.1 The Radical Concept of Arrows That Stay On The Shapes

A key aspect of the Id system is that there is an object *graph*. That is, obj-dicts can have entries pointing to other obj-dicts, without restriction to a tree structure. Drawing arrows to denote this is a no-brainer (and easy on paper), so I wanted it in my substrate for Id.

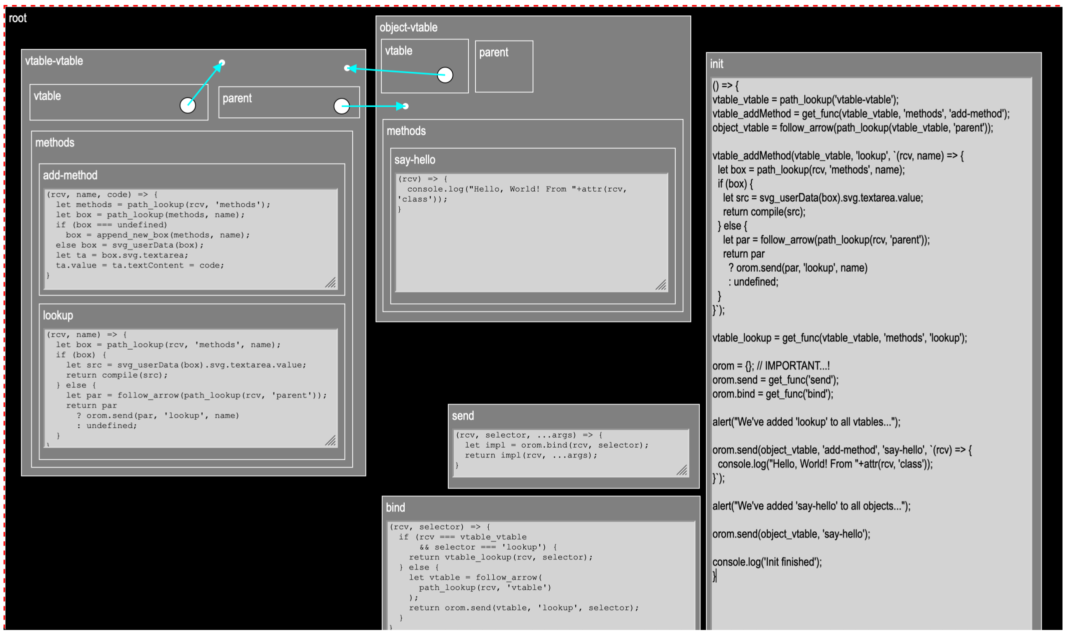
Luckily, Scalable Vector Graphics (SVG) was at my disposal, which could be persuaded to display `<line>`s over the `<div>`s. But another key feature of my intended substrate was to be able to rearrange and resize the boxes. So I would also need to detect changes to the position and size of an element.

Bizarrely, there is no such facility provided for HTML elements. This, despite the fact the browser *needs* this functionality hence it must reside *somewhere* inside the black box.

Reluctantly, I stuck with my plan B: each object has a numerical ID and pointers are just fields containing a number, followed using a `deref()` function.

At this point it was starting to look like a mistake not to have done the whole thing in SVG. I would gain full graphical freedom, though also lose some benefits of the browser's managing it on my behalf. I already knew from experience the surprising complexity of a DIY approach to layout, model-view updates, and interactivity. But such an exercise would be an opportunity to carefully observe this tedium, and crystallise some of my intuitions about why it is so consistently frustrating.

2.2 Id as SVG trees



```
(rcv, name, code) => {
  let methods = path_lookup(rcv, 'methods');
  let box = path_lookup(methods, name);
  if (box === undefined)
    box = append_new_box(methods, name);
  else box = svg_userData(box);
  let ta = box.svg.textarea;
  ta.value = ta.textContent = code;
}
```

```
(rcv, name) => {
  let box = path_lookup(rcv, 'methods', name);
  if (box) {
    let src = svg_userData(box).svg.textarea.value;
    return compile(src);
  } else {
    let par = follow_arrow(path_lookup(rcv, 'parent'));
    return par
      ? orom.send(par, 'lookup', name)
      : undefined;
  }
}
```

```
(rcv) => {
  console.log("Hello, World! From "+attr(rcv,
'class'));
}
```

```
(rcv, selector, ...args) => {
  let impl = orom.bind(rcv, selector);
  return impl(rcv, ...args);
}
```

```
(rcv, selector) => {
  if (rcv === vtable_vtable
      && selector === 'lookup') {
    return vtable_lookup(rcv, selector);
  } else {
    let vtable = follow_arrow(
      path_lookup(rcv, 'vtable')
    );
    return orom.send(vtable, 'lookup', selector);
  }
}
```

```
() => {
vtable_vtable = path_lookup('vtable-vtable');
vtable_addMethod = get_func(vtable_vtable, 'methods', 'add-method');
object_vtable = follow_arrow(path_lookup(vtable_vtable, 'parent'));

vtable_addMethod(vtable_vtable, 'lookup', `(rcv, name) => {
  let box = path_lookup(rcv, 'methods', name);
  if (box) {
    let src = svg_userData(box).svg.textarea.value;
    return compile(src);
  } else {
    let par = follow_arrow(path_lookup(rcv, 'parent'));
    return par
      ? orom.send(par, 'lookup', name)
      : undefined;
  }
}`);

vtable_lookup = get_func(vtable_vtable, 'methods', 'lookup');

orom = {}; // IMPORTANT...!
orom.send = get_func('send');
orom.bind = get_func('bind');

alert("We've added 'lookup' to all vtables...");

orom.send(object_vtable, 'add-method', 'say-hello', `(rcv) => {
  console.log("Hello, World! From "+attr(rcv, 'class'));
}`);

alert("We've added 'say-hello' to all objects...");

orom.send(object_vtable, 'say-hello');

console.log('Init finished');
}
```

Figure 2 Id/SVG: Obj-dicts are moveable and resizable nested boxes, referencing each other via *real arrows*.

In Id/SVG, shown in Figure 2, obj-dicts are encoded as nested SVG `<rect>`s and other elements, reminiscent of diSessa's Boxer [dA86]. This was a significant departure from the table representation, and even though SVG supports (some) nested HTML via `<foreignObject>`, I actually preferred the possibility of multiple levels of nesting.

Still, this version was far more challenging and took much longer to reach a satisfactory state. Yet it is precisely this drudgery that brings me to a better understanding of this paper's question: *what has it taken?* I shall discuss this in the form of broad patterns or themes that stand out to me from my development experience, hammered home by these Id implementations.

3 Typical Requirements Of Common Software (and the work we must do to meet them)

The "common case" of software present in our daily lives shares certain properties, such as being graphical and interactive. Such are expectations that "end-users" hold, consigned as they are to merely *consume* what programmers give them. But if we want to make "programming" more like "using", such expectations on *use* at least need to be acknowledged.

In this section, I will present these and other seemingly *inevitable* demands of normal software, exemplified by Id/SVG. I will comment on how our programming platforms measure up to the task, including my chosen platform of JavaScript and Web technologies.

3.1 Retained-Mode Vector Graphics

Most software is designed for the subset of people who have a colour display they can perceive. So right away it is going to require ways to draw coloured shapes. There are usually libraries for this (though note: not part of the language), but some only provide *immediate mode*: commands to instantaneously rasterise pixels to a buffer. This is not enough for modern software, as we often expect animation, or at least to see things change as we interact. Most often we wish to see *small changes* to the *same* shapes, rather than completely different shapes altogether; the reification that this requires to persist between frames, is known as *retained mode.*

On this requirement, SVG fits the bill very well. Although it is not part of the JavaScript language *per se*, it is a standard and widely supported technology of the Web *platform*. We can observe that anyone with a browser *in principle* has access to a powerful vector graphics editor—just one with no GUI.

The SVG tree has the nice properties of the DOM, such as updating the display when shape parameters are changed. This is well-adapted to "I/O-bound" software like mine, where things change only in response to user input. If I wanted animation, this would boil down to a regular "advance simulation" signal, and would require setting up some rendering loop. Alternatively, there is the W3C's chosen ontology of CSS animations, but see Section 4.4.

3.2 Basic Assumptions About Physical Objects

In any software making use of vector graphics, there is usually some level of "physics" expected by users. This need not be nearly as exhaustive as the word "physics" might imply, as in e.g. physics engines for games; I feel it is important to recognise it for what it is instead of conceiving physics as an inherently complex thing to be found only in specialised simulations. For example, pretty much all mobile apps have what could be called “phone touch physics” where menus and screens slide in and out.

All humans learn a basic set of expectations about the things they see around them. Some of these, such as “things fall down”, are not generally appropriate to software UIs—perhaps because the screen has a role in our lives a more of a table work surface rather than a vertical wall, even if it is vertical in real life. The level of physics in software tends to not involve force, or mass, or very much at all, merely position and space; we could call it “geometric physics”.

One thing that all usable software must do, for example, is avoid crushing many visually complex shapes, such as lines of text, into the same (unreadable) region. Such concepts of “solid objects do not intersect” or “only things at different layers may overlap” are basic rules inherited from the real world of graphical presentation.

I feel the need to point this out, because by default the computer does not know even the most obvious things about how space works, so we must laboriously algorithmise this intuitive concept. This is not only true in the case of 2-dimensional visual domains, but even in the 1-dimensional case of memory allocation. The physics of 1D memory are something like this:

- This number range 0000–FFFF is like a space (addresses = points)
- Every point has at most one owner block (no overlap)
- These blocks are contiguous, finite ranges (1D boxes)

Far from being a niche topic in games and graphics, spatial partitioning algorithms and data structures have surprising relevance to more ordinary software. Both memory allocation and graphical layout are essential to today’s; shame that only one of those has been recognised as such—and made part of the standard libraries of programming languages.

3.2.1 Translationally Rigid Bodies

When you have both a screen and a pointing device (e.g. touch or mouse), immediately it becomes worth having ways to move things around in at least a minimally realistic way. We can debate the appropriateness of Direct Manipulation for various situations. But it does make a lot of sense in simple cases, such moving around subdivisions of space (e.g. windows) or elements of a graphical design.

In Id, the obvious candidate for this is the obj-dicts, plus all nested boxes in Id/SVG. If I move the top-level rect, then I expect its children to move with it. This is simply the translational physics of **rigid bodies**: “this set of points all move together”. Of course, proper rigid bodies might also rotate and have mass, but this is usually undesirable for UI elements.

Translational rigidity can be expressed as the points X and Y always having the same displacement from each other. Or, when one point is moved, the rest also move by the same delta. This is a problem of **preserving the relationship over time**, which was a significant area of Id/SVG.

3.3 Maintaining Relationships Over Time

The model of state-mutation present in most imperative languages is what I call “dumb” state. The language provides an affordance to change any part of the state to a new value, but nothing else.

What more could there be? Well, in *every* software system there are certain rules, or “invariants” of **internal consistency**, such as “translational rigidity” above. Often, changes to any part of the system are permissible, but only if connected or dependent parts of the state change in response.

The job of keeping track of who depends on whom can fall either on the programmer, or the computer. If the programmer has to do this, they can only go so far managing and simulating in their head. As systems grow more complex, it is only natural to try and make the computer more intelligent to do this work. What I am building up to is that whenever we (or I) consider constraints, “reactive” programming, or the “Observer” pattern as things you only wheel out *on special occasions*, we only deceive ourselves into doing the *same work* less explicitly. It seems that such “live state” should be the expected common case for software development.

If a platform does not provide a means to causally link and unlink bits of live state, then this must form part of the standard boilerplate. Such was the case in Id/SVG: the polyfilled “Observable” class is the most widely used. It wraps a current value and a list of subscribers, notifying them when it changes.

Getting an object to follow the mouse pointer (e.g. when dragging) is *conceptually* very simple: an “always equal” relation. In Id/SVG founded on live-state, this can be expressed in much the same way:

```
subscribe(object.position, pointer.position);
```

By default, an Observable A responds to a change from Observable B by adopting B’s new value. So by subscribing the object’s position to the pointer’s, pointer movements copy the new position to the object.

3.4 Nut-Cracking With Sledgehammers

Speaking about vector graphics, physics, layout and constraint maintenance might give the impression of high *conceptual* complexity at the heart of even simple software. This is not quite true, which makes it all the worse that there is yet still immense *implementation* complexity.

We are conditioned to only think of these in their most general forms. But the “vector graphics” I use in Id/SVG are just rects, lines, circles and text; a fraction of the full capability of SVG. The “geometric physics” I use is dwarfed by fully general 2D or 3D physics engines. The only layout algorithm I had the patience to implement was a simple way to expand a list of boxes to fit in a new child at the bottom. The affordance to place and size boxes *manually* is a convenient substitute, when required infrequently. Yet search for material on layout algorithms, and it can seem like Fully General Linear Inequality Solvers like Cassowary [Bor+97] are all there is.

The inevitable requirements I suggest here, do *not* necessitate Fully General anything. In fact, such generality might make it *more* cumbersome to express what I wanted in Id. As the old wisdom goes, there's no point expressing a simple regex search as an arbitrary Turing machine; my boxes don't *have* a moment of inertia or a mass and I don't *need* a linear optimisation solver for my space management—for the time being. Under the theme of domain-appropriate tools, I think it is worth designing interfaces for *smaller-scale* instances of these areas and exploring what they are still capable of expressing.

4 Patterns and Polyfilling

The message of the previous section is that existing platforms are often at the wrong level of abstraction for the requirements of common software. I recognise that they are reasonably well-adapted to batch mode file I/O tasks, but that they fail for the *common case* is a problem. There is largely the same setup per project just to get basic functionality:

- Here is how I shall describe shapes
- Here is how I make these shapes move together
- Here is how I maintain internal consistency as the user unpredictably changes things

This burden either falls on the author, or on the wider community to build and maintain higher-level frameworks, syntax extensions, etc. In this paper, I refer to this process as "polyfilling", with an emphasis on the DIY, individual level.

It is true, we already have a term for bringing into existence some software feature that isn't already there: programming. The difference is that polyfilling is about filling in *boilerplate*, i.e. functionality *that should have been there in the first place, but isn't*. This injects some subjectivity and value judgement into the term. But ultimately, all platforms are designed with certain features "out of the box" and leave other features for us to implement "if needed".

When the *normal* problem domain "requires batteries", yet the tools available say "batteries not included", it is quite reasonable to want the batteries to be part of the platform. Section~6.1 will expand on this further, but here I will list the "batteries not included" I found myself polyfilling in Id/SVG.

4.1 Wrapping and "user data"

The classic example of polyfilling is finding that JavaScript arrays do not support some familiar operation. For example, this used to be the case with the `map` function. Yet JavaScript lets you *directly augment* the `Array` class with the new operation, even though `Array` is "part of the language":

```
Array.prototype.map = function() { … }
```

One can do this to all objects, even those of Web APIs. For example, I use it to connect SVG nodes to the Id system: when a `<rect>` is created, it is "annotated" with a `userData` pointer to the box that it is part of. Then, when clicked, the box can be found immediately.

This could be described as the box "wrapping" the `<rect>`, but risks implying that the `<rect>` merely needs to *live inside*, or *be referenced by*, the box. In this case, the *reverse* association is also needed (i.e. mutual pointers); clicks can only enter the system *through* SVG in the first place. What is significant here is that JavaScript lets us add such a link to an entity that *we did not design*.

This term, "user data", often crops up in libraries with the same idea: to associate arbitrary data with an API object. But in languages that do not permit such *unanticipated* "annotation", this has to be explicitly *designed in* ahead of time. If it wasn't, then it has to be done in a roundabout way—for example, a separate `userData` lookup table, indexed by the memory address of the API object.

4.2 Positioning and Sizing

The simple desire to move and resize boxes with the mouse motivated a lot of the concepts in Sections 3.2 and 3.3. This problem could be considered a microcosm of Id/SVG: what's a natural way I *conceive* of this behaviour, and could I implement it that way?

It starts with a consideration of translational rigidity. In its most primitive form, this is a relation between two points. Thus it is natural to draw a line or "rod" between them. It seems that this rod transmits changes in one of its endpoints directly to the other endpoint. Since they both feel the same deltas, the displacement vector between them is preserved (Figure 3).

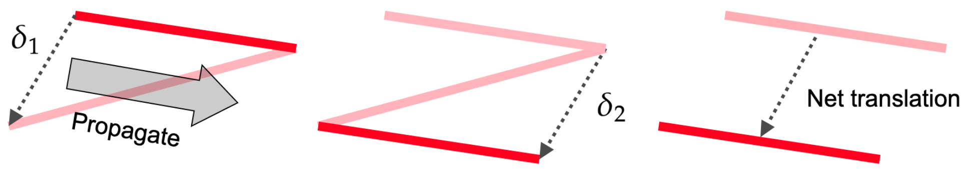


Figure 3 Fully rigid rods transmit changes in one end to the other end.

I like to see what I'm doing, so I wanted these rods to be visible and thus somehow *present in the SVG*. For this, I have a Point class that is used wherever manipulable points (SVG circles) are needed, and a Rod class that draws a `<line>` and transmits endpoint deltas across its length.

Resizing of boxes could be achieved through rods that stay horizontal or vertical. In the language of "small differences" spoken by the live-state infrastructure, this is expressed as a rod "transmitting deltas" in the vertical and horizontal, "absorbing" the other component into itself (Figure 4). Mirroring a DOM rect to these rods is as simple as subscribing its width and height to horizontal and vertical rods' `length` Observables. This way, boxes can be resized from whatever corner is convenient.

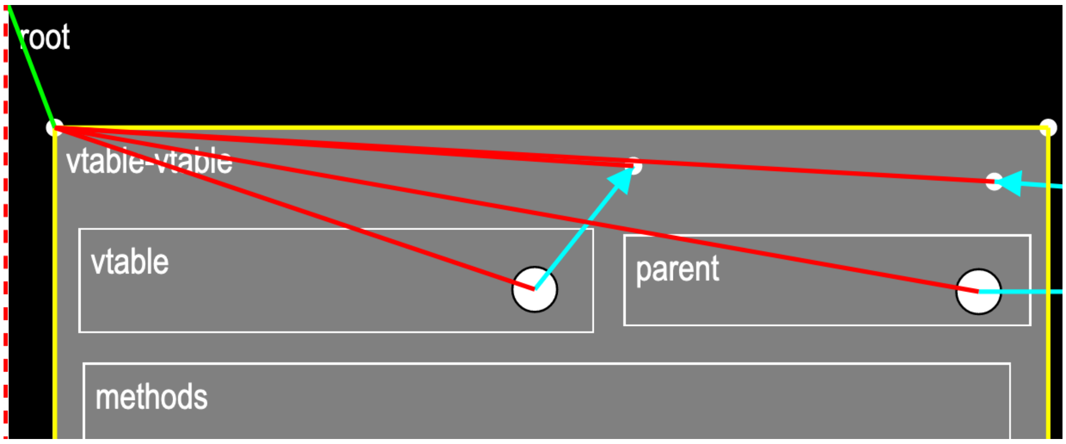


Figure 4 The yellow rods on the box border are "half-rigid": they transmit horizontal or vertical changes, but not both. The green rod in the top-left absorbs all changes from an endpoint into itself, visualising the displacement vector of the child box from its parent. The remaining red rods are fully rigid. A line of CSS can reveal this "scaffolding" which is normally hidden for users.

Unfortunately, with these rods came possibly the most frustrating technical challenges of the entire system. Initially I hoped to move boxes as rigid bodies by temporarily making their border rods rigid. However, the four border rods form a cyclic graph, as rods are not directed. This, coupled with the unintended depth-first semantics of Observable notification (a result of JavaScript function calls in a loop), led to duplicate deltas applied twice and other nightmares. This is the tip of an entire research iceberg stretching from Functional Reactive Programming to internet routing and distributed algorithms.

I had to shelve this investigation in the interest of continuing with the rest of the system, but I did manage to surmount this through kludging and compromise. So I do not know whether these problems are merely a consequence of some design decision I could change to escape it, or if they are intrinsic to my (modest) UI goal.

4.3 Visible Coordinate Systems

Rigidity in a flat world of sibling shapes is somewhat straightforward. However, rigidity in the SVG world is more involved.

First of all, SVG shapes (e.g. `<rect>`) are strictly *leaf* nodes of the DOM. So if I wish to nest boxes within boxes, the visible box `<rect>` must be a mere *accessory* to the nestable element, in my case a `<g>` (group). This means that instead of resizing the `x`, `y`, `width`, `height` attributes of the `<rect>`, only its `width` and `height` change, along with the `transform` attribute of its *parent* `<g>`. This was not too bad; just subscribe this attribute, instead of the `<rect>` position, to the top-left Point handle.

All child elements of a node transform with it, so already SVG has baked in a basic facility for translational rigidity. This is only available as a tree hierarchy,[7] but it is still useful. However, it conflicts with my early decision to have Point objects all share the global co-ordinate system (this was to ensure that simple relations, such as a point following the mouse pointer, are not infuriating to express.) Still, it was necessary in the case of certain elements—especially those which must transcend the tree structure altogether, like arrows between boxes—to bite this bullet, one way or another.

Again, I return to how we tend to work things out in the freedom of paper. Co-ordinate systems, here merely positionally displaced, have their origins here and there and have vectors between them. The rods thus far let me visually express relations between global Points; now was a question of expressing one global Point as a displacement from another (the `<g>` transform). New rod Observables `p2_from_p1` and `p1_from_p2` do the vector subtraction, which can then be propagated as local co-ordinates to children. It is nice to express the relation (as well as see it!) this way (Figure 4).

4.4 Context-appropriate ontologies

Each API has its own conventions, including a way of naming and structuring expressions—an ontology [Bas18]. The One-Size-Fits-All approach is exemplified in such interfaces. For example, in SVG we express a rectangle by `<rect x="10" y="10" width="600" height="400">`. The SVG specification *defines* to the user that a rect simply **is** a top-left corner, a width, and a height—and that's it. However, this SVG-approved parametrisation of a rectangle is far from the only one, and thus is, unsurprisingly, ill-fitted to some contexts.

For example, I find it natural to resize boxes by dragging any of their four corners, so I wanted this in Id/SVG. In this context, a "rectangle" is *seen as* four points: top-left, top-right, bottom-left, bottom-right. Obviously this is not a *minimal* description, since given e.g. the top-left and bottom-right, the other two points can be inferred. But one way or another, to be able to drag any of them, all four points must be present at *some* level. This alternative ontology was polyfilled in the form of a "rect controls" class that can be attached manually to any SVG `<rect>`. The `x` and `y` are subscribed to the top-left Point[8]; `width` and `height` are subscribed to Rod lengths.

Another example is to be found in the DOM's event listener model. Conceptually, many "events" are in fact changes to the state of some physical device. And both keyboard keys and mouse buttons, for example, have two states—pressed, not pressed—which ought to make them *interchangeable* to some extent. Indeed, this is why there is such a thing as "key mapping"[9] in PC games. But the official ontology of the Web makes it nontrivial to do this.

[7] This highlights the mismatch between the tree-based DOM and any system that is graph-structured.

[8] In the usual case where the `<rect>` is part of a box, the top-left instead controls the parent `<g>`'s `transform`—but the idea is the same.

[9] For example, the player can re-assign the action "shoot" from its default mouse button to a keyboard key, or another action from keyboard to mouse, as it suits them.

To start with, the situation is modelled not as the *changing* of some time-varying property, but instead as a sort of Cartesian product of subroutines. Rather than, say, a piece of live-state for the left mouse button (LMB), we get onmousedown and onmouseup. Thankfully we do not have onAdown/onAup, onBdown/onBup, ... all the way to onZdown/onZup, but only onkeydown/onkeyup. Yet this is just one of the many possible ways to slice this 3-dimensional[10] space.

In Id/SVG I did not quite want to re-map keys, but I did often want to have things follow the mouse when dragged. In order to do this, I reified the mouse pointer and its position, letting me write subscribe(point.position, pointer.position). The Point has an is-considering-me? Observable wrapping onmouseover/onmouseout, and the LMB is reified into left_mouse_button_is_down to be explicit. The aforementioned subscription is set up whenever is-considering-me? and left_mouse_button_is_down become true, and torn down otherwise. I tended to think of this in the form "subscribe to pointer *only when* pointer is-considering-me *and* LMB is down", but I could live with this notation as a future polyfill in JavaScript.

The way these things are connected to the browser's event listeners could be called "device drivers"—an approach described in [Hag10]. It amounts to translating information from the Web's ontology into that of my substrate, as early as possible:

```
svg.onmousedown = e =>
  if (e.button === 0) change(left_mouse_button_is_down, true);

svg.onmouseup = e =>
  if (e.button === 0) change(left_mouse_button_is_down, false);

svg.onmousemove = e => {
  let r = svg.getBoundingClientRect();
  let pos = vsub([e.clientX, e.clientY], [r.left, r.top]);
  change(pointer.position, pos);
};
```

It takes some frustration and experience to get used to the idea that you have a right to polyfill in alternative representations. Before I came to this conclusion, I used to twist my head around translating my intention into the x,y,width,height parameters, and un-translating when reading back the code I had produced. Once you get used to having to adapt your mental imagery to a single way of doing things (i.e. learning to code), it makes sense to simply expect to see more of it—especially when you know you are new, surrounded by veterans who see no problem, and so on. Nowadays, I take the position that these are simply *widespread* failings of our way of doing things, instead of *our* failure to adapt to the way software is.

What would it look like to support multiple ontologies? Na"ively, there are two answers: anticipate the possibilities ahead of time, or support users adding their own. It is unclear if we can do better on the latter than simply "support polyfilling". As for the former, anticipating the diversity of ways someone might look at the world is generally doomed to fail. But in the special case of fairly *formalised* concepts such as

[10] Device (mouse, keyboard), sub-device (button, key), state (up, down)

geometrical shapes or mathematics, I could suggest that simple *under-specification* is the root of the problem in SVG. Instead of the specification explaining in English that "x and y are the co-ordinates of the top left-hand corner…", it might be better to make these relations machine-readable or *embodied* in the API. For the rect this might look like:

- A rect is…
- a polygon (to be defined elsewhere)
- defined by 4 *degrees of freedom* x y width height (internal representation)
- where there are 4 *vertices*, all points
  - [x,y] called top-left
  - [x+width,y] called top-right
  - [x,y+height] called bot-left
  - [x+width,y+height] called bot-right

The hope is that if we then specify enough information—say, the bot-left and top-right—then the runtime has all it needs to derive its internal 4 degrees of freedom.

In a crude sense, I have successfully anticipated the most obvious ontologies of a rectangle here. However, I missed out the "centre plus half-width and half-height" formulation, among others. Is this a futile effort even for precise mathematical knowledge structures, or could enough formalisation[11] of Euclidean geometry in the Web platform put an end to this sort of polyfilling?

There is, in fact, a part of the SVG specification [SVG11] that comes *frustratingly close* to the above. It spells out how the <rect> parameters "reduce" to more primitive line-drawing steps, including expressions for the four corners in terms of x,y,width,height. The problem is, this reduction is still described in *natural language* for a human implementor, missing the potential of such a formulation.[12]

It is worth admitting that there is is a significant shortcoming of my polyfill here, and perhaps throughout. It has taken the form of *overriding* the default ontology, *replacing* it with the one I preferred. From my perspective, this is fine. But if another person were to join in the development of Id/SVG, they would be stuck in the same situation I was in, unless they fully agreed with my ontologies.

The desideratum of "ontology co-existence" is very much an open research problem. [Bas18] gives a taste of the thorny complications unaddressed by a "Semiotic Programming" solution [Sha18], while [Kel17] points out how the idea of "linking" is unconcerned with whatever language compiled to the object code; language-agnosticism is one salient example of ontology co-existence. This is especially clear if we agree with the latter author's view that "which language" ought to be an *implementation detail*, that languages ought to be treatable as *different views* onto the same thing.

[11] A related question is whether type systems and other auto-reasoning formalisms are trapped in a doomed quest for "closed-form" AI, representable as a LaTeX formula.

[12] The point here is that a machine-readable description could easily remain human-readable, but a natural-language description is not easily machine-readable.

These considerations did not occur to me because this project is very idiosyncratic to my interests, at least in its initial stage. I always worked on the assumption that I was the only developer. However, a future Id system in a mature state should by no means be bound to this fact. It is also worth considering *myself in the future* as a different agent, with different ontology preferences. In that case, the method here will need to be re-examined.

4.5 Extensional Functions

Time and time again we come across the same pattern of partitioning system state: trees or graphs of dictonaries, a.k.a. Maps, a.k.a. associative arrays. I am talking about filesystem paths `/path/to/some/file`, Python / Java modules `com.example.pkg.subpkg`, JavaScript objects `window.my_obj.component`. The common case is an association of a textual name to an arbitrary value. I find it useful to see this as a mathematical "function" defined *extensionally* by listing its input/output mappings—this opposed to an *intensional* definition such as $x \mapsto 2x + 3$, or a computer program.

Extensional functions are perhaps the most basic form of Knowledge Representation, and match natural language very well. "The bicycle's wheels' spokes are silver" straightforwardly translates to a function equation

```
root (bicycle) (wheels) (spokes) (colour) = root (silver)
```

That is, whatever object is the output of `silver` in the top-level `root` function, the output of `colour` (in the function on the left) points to the same object. The ability to partition a system in this way enables what [Bas+16] calls a "natural co-ordinate system" for a piece of software, crucial for understanding and adaptability by others.

It seems that this way of expressing the "parts" of a system is an inevitable requirement of any programming substrate. Some languages, such as C, do have static, *compile-time* associative arrays (`struct`s). In my experience this is usually not enough, and it's necessary to bring in a library or clutter the code with a home-grown approximation to dynamic ones. Some parts of the Id authors' C code were confusing until I realised they were just the guts of a basic associative-array implementation; when I switched to JavaScript, these lines vanished.

Perhaps another strength of JavaScript is its low *concrete syntax cost* for *instances* or *literals* of associative arrays. Writing or reading

```
a = {
  b1: { c1: z, c2: y },
  b2: { c3: x, c4: w }
};
```

is more "What You See Is What You Get" than the imperative-style

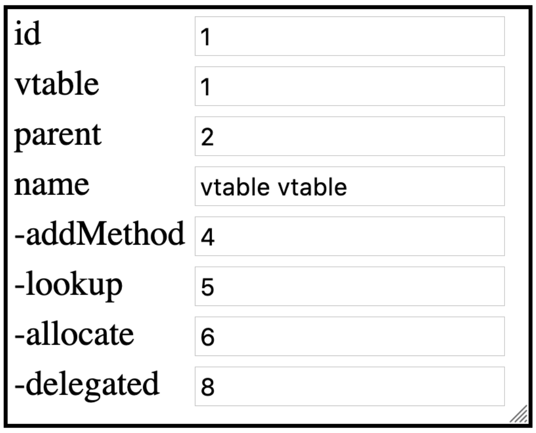
```
a = new Map();
a.set('b1', new Map());
a.get('b1').set('c1', z);
a.get('b1').set('c2', y);
a.set('b2', new Map());
a.get('b2').set('c3', x);
```

```
a.get('b2').set('c4', w);
```

The latter style is unfortunately still required in JavaScript for extensional functions with *non-string* inputs.

My original flat, tabular representation in Id/HTML did support a single level of such “extensional functions”, but no more. In other words, the output of such a mapping could not be a further mapping itself. This was problematic because vtables, conceptually, have two levels of such nesting: the top-level fields, and the “methods dictionary” which contains its own input-output pairs. To distinguish between these, I actually stored method mappings with an ad-hoc “-” character (Figure~5).

By contrast, after switching to the fully nestable box substrate in Id/SVG, I could directly express the model I was thinking of (Figure 6). If I had stayed in HTML, there is a good chance I would have had to polyfill in extensional functions—whether through nested <table> elements, additional “-” characters or something else.



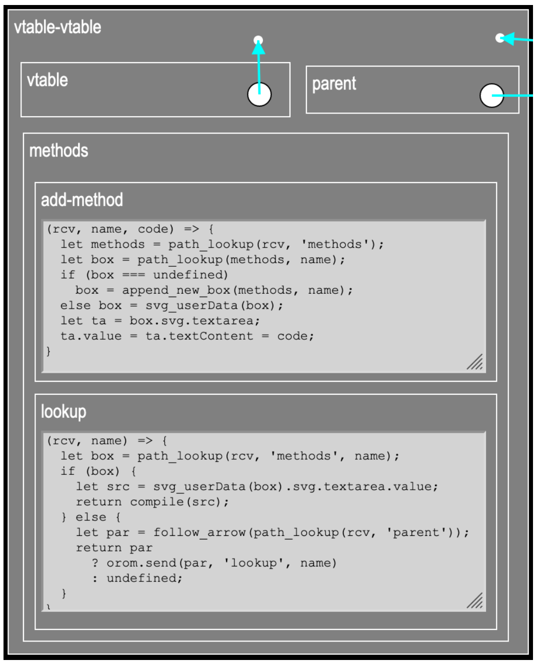
id	1
vtable	1
parent	2
name	vtable vtable
-addMethod	4
-lookup	5
-allocate	6
-delegated	8

Figure 5 Id/HTML: use of hyphenated `-lookup` to signify a *method* called `lookup` instead of a property like `vtable`.

4.6 Persistence

This refers to exposing structured program state to the user. This data can then be saved and used to restore the system at a later date, but it can also be tweaked with corresponding changes reflected in the system.

Persistence was absolutely necessary to continue Id/SVG development, past a certain point. This is because, upon discovering a bug and fixing it in the source code, the web page must be refreshed and started anew. In the beginning, when verifying that box drawing with the mouse is working correctly, this is not much of a problem: upon refresh, the blank initial state is restored and I could draw again. But as the substrate matured, and I began to implement parts of the target system (Id)—the cycle of finding a bug, tearing down the system, refreshing and losing work, and manually building it up again, proved frustrating. Because the system could only be patched externally and restarted, there needed to be some way to persist changes which live in the DOM, rather than the source files.



```
(rcv, name, code) => {
  let methods = path_lookup(rcv, 'methods');
  let box = path_lookup(methods, name);
  if (box === undefined)
    box = append_new_box(methods, name);
  else box = svg_userData(box);
  let ta = box.svg.textarea;
  ta.value = ta.textContent = code;
}
```

```
(rcv, name) => {
  let box = path_lookup(rcv, 'methods', name);
  if (box) {
    let src = svg_userData(box).svg.textarea.value;
    return compile(src);
  } else {
    let par = follow_arrow(path_lookup(rcv, 'parent'));
    return par
      ? orom.send(par, 'lookup', name)
      : undefined;
  }
```

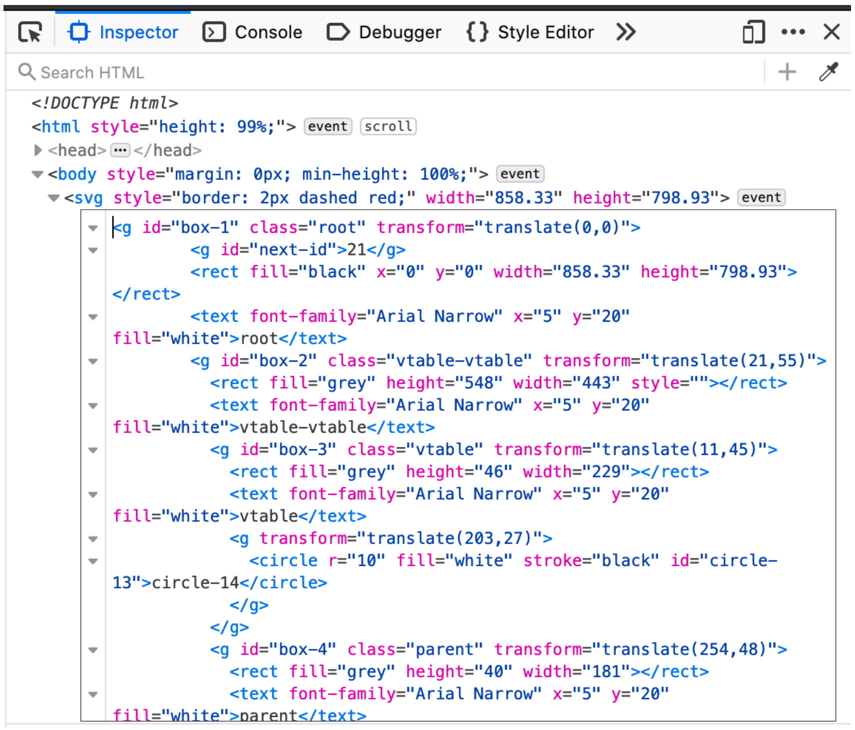
Figure 6 Id/SVG: the vtable box has a methods box, and that's where the method boxes go.

Normally, this can be as simple as autosave to the filesystem. But the Web platform is very wary of this,[13] so the solution I turned to was manually copying the markup in the browser's inspector (Figure 7).

This required a slight change towards an architecture where the all the data required to reconstruct the system's current state is contained in the inspector HTML, as opposed to hidden JS properties. Where previously "boxes" were created first as invisible JS objects responsible for some SVG, now it was the other way round. When a rect is clicked, the system must look at some SVG and interpret it "on demand" as a box (although this helper object, once created, can be cached in the SVG nodes).

Persistence seems to be a weaker cousin of **externalisability**, defined in [Bas+16]. As it stands, the system does not quite qualify as externalisable. When making changes to the HTML in the element inspector, the system's behaviour *ought* to adjust to match, but this is not currently guaranteed. Depending on the ability to listen for changes in node attributes or children, this may remain the case.

[13] As anyone who learns WebGL can attest to, when they discover they must run a local Web server to provide image files for textures since any filesystem requests will be rejected for security.



```
<!DOCTYPE html>
<html style="height: 99%;"> event scroll
▸ <head>⋯</head>
▾ <body style="margin: 0px; min-height: 100%;"> event
  ▾ <svg style="border: 2px dashed red;" width="858.33" height="798.93"> event
<g id="box-1" class="root" transform="translate(0,0)">
        <g id="next-id">21</g>
        <rect fill="black" x="0" y="0" width="858.33" height="798.93">
</rect>
        <text font-family="Arial Narrow" x="5" y="20"
fill="white">root</text>
        <g id="box-2" class="vtable-vtable" transform="translate(21,55)">
          <rect fill="grey" height="548" width="443" style=""></rect>
          <text font-family="Arial Narrow" x="5" y="20"
fill="white">vtable-vtable</text>
          <g id="box-3" class="vtable" transform="translate(11,45)">
            <rect fill="grey" height="46" width="229"></rect>
            <text font-family="Arial Narrow" x="5" y="20"
fill="white">vtable</text>
            <g transform="translate(203,27)">
              <circle r="10" fill="white" stroke="black" id="circle-
13">circle-14</circle>
            </g>
          </g>
          <g id="box-4" class="parent" transform="translate(254,48)">
            <rect fill="grey" height="40" width="181"></rect>
            <text font-family="Arial Narrow" x="5" y="20"
fill="white">parent</text>
```

Figure 7 To save the state of the system, the SVG group corresponding to the root box is copied and pasted inside the HTML file's <svg> element.

5 The Id system as a part of the solution

The Id system was designed with a goal of eliminating the "artificial" distinction between implementation language and end-user language, by means of a mostly self-defining, or "meta-circular" object model. This general way of working on a piece of software "by means of itself" is easy to agree with, even if OOP is not to everyone's taste. It is an open question whether Id's approach could be applied to other programming styles.

The allure of meta-circularity here is not merely in being "cool", but that it paves the way to end-user empowerment. This is somewhat misleading because in Id, these "end-users" are actually programmers. However, its purpose is to free a programmer's dependence on some distant and busy[14] language designer. It seems plausible that this is a step on the way to enabling *creation* of a piece of software which non-programmers do not depend on us for.

I emphasise that this is the *allure* of Id. However, there are some significant practical issues that must be overcome or clarified first.

[14] Not to mention *unelected?* "Take Back Control!" (jokes aside, in this context it makes a lot of sense.)

5.1 Minimal descriptions

The Id paper was part of the STEPS project of Alan Kay's VPRI.[15] This project argued that the immense level of "accidental complexity" present in software implementation could be reduced, and Kay himself dreams of an end result analogous to a "Maxwell's Equations" of software. That is: the behaviour of electromagnetic fields can be represented in four short equations that fit "on a T-shirt".

A self-hosted LISP interpreter fits on a page. Could we aim at a similar "fundamental description of software" that fits on something less than millions of lines of code?

This argument as stated suffers by glossing over an important fact. Maxwell's equations certainly do fit onto a T-shirt, but most people will not be able to explain what they mean. What typically amounts to years of study is compressed into those mathematical symbols, and the learning material involved most certainly does *not* fit on a T-shirt. The obvious *reductio ad absurdum* is where we encapsulate these equations under a single symbol, $\mathscr{M}$. $\mathscr{M}$ is defined as "Maxwell's Equations are true". Ta-da—this fits on a coin, but good luck doing anything with it.[16]

I say this not to dismiss the argument, but to highlight the *actually hard part* of getting a "concise description" of some system; defining complexity away into a symbol helps us no more than naming the solution to an equation "x". There is a connection with data compression: even if the data is successfully compressed into a smaller file, the size of the compression *program* should be added as well. What matters is to reduce the *combined* size of notation and substrate.

Further, there is perhaps a risk of optimising for *formal* rather than *practical* minimality (e.g. the Turing machine). Id's "minimality" does not necessarily translate into "simplicity". It suffers from the same *cognitive* complexity, or need for study, as Maxwell's Equations; I cannot stress enough the amount of effort I have put in to wrap my head around the self-referential "vtable vtable" and the task of self-implementation. An overall better system might be one which is easier to pick up or understand, even if the number of formal objects is not as minimal.

In the conclusion of [PW06], the authors note that "it is not necessarily a friendly model for hand-written code", suggesting its use as a compilation target. In a similar vein, it could function as the kernel of a much more familiar system (on the surface)—it is, after all, supposed to be a vehicle that other things sit on, rather than the final user interface itself. In fact, this is precisely the approach set out in the related paper [Piu06].

[15] Viewpoints Research Institute

[16] In fact, this is almost achieved by the formalism of Geometric Calculus, which reduces them to only one equation.

5.2 Self-implementation

Said related “COLAs” paper expands on Id, giving it a “structural” role complemented by a LISP-like programming language. Section 6.1 sketches out the intended “bootstrapping” process, ending with a self-sufficent, self-hosting version of the system.

However, this task again suffers from the same cognitive complexity as any other self-referential circle. This is even more so for me, having made the complexity of graphics and interaction somehow still “part of the system”. Figuring out exactly how the authors’ bootstrapping process of their wholly *language-based* system maps on to my task is, as far as I know, uncharted territory.

Finally, in [Bas18], there is a warning against “obsession with completely homogenous systems” written in themselves. If this approach is doomed then obviously I want to take a different one, but the argument against it seems to hinge on what constitutes “failure”. It considers Smalltalk and LISP as “unsuitable”, yet the authors of Id clearly think the opposite. The disagreement probably hinges on “unsuitable for *what*?” and it would be clearer if the following two questions were answered:

1. Is there a difference in (final, intermediate) goals between the two views?
2. Could systems like Id and COLAs plausibly succeed at their own stated goals?

6 Conclusions and future work

6.1 What did it take, and why?

It takes a lot of work to create in a substrate that feels suited to the domain. Much of this work involves filling in the machinery necessary to an awful lot of software, rather than the ways one’s domain *differs from* this common case.

In an ideal world, there would be no accidental complexity, no boilerplate, no polyfilling. But this can’t be the same as saying there would be no *work* to do—that sounds like a world where *essential* complexity has also been removed.

Instead, we can note that software ecosystems typically centre around a “core”, such as a language, with a surrounding “periphery”, such as libraries not bundled with the core language. The core (language syntax, semantics, standard libraries) acts as a common platform uniting the community; the periphery consists of functionality that is not “built-in” to this core, both realised as software (e.g. libraries), and that which is as-of-yet unrealised or nonexistent.

There is a constant process of negotiation determining what should be part of the shared core versus the responsibility of the periphery. But at any given time, every community draws the line somewhere.

To a first approximation, what is “built-in” encompasses the features and concerns that are *common* to the entire community. Features that are of minority or niche use belong outside; it is one’s own responsibility to implement them, or to integrate with an existing implementation.

What does it take to create with domain-appropriate tools?

Perhaps in an ideal world, someone could realise their vision in software by focusing all their effort on what makes their idea *unique*, or what is *idiosyncratic* to it. In other words, they would only be responsible for that part of their idea which:

1. It would be unrealistic to expect the wider community to have *thought of already*, and
2. It would be unfair to expect the wider community to *build on his or her behalf.*

If the core Web platform (particularly JavaScript) is meant *for* supporting "web apps", and this is indeed how it is used, then it seems it has not yet fully absorbed the functionality common to this usage. At present, this is simply a surprise, or a puzzle, and it might simply be a matter of time before it catches up.

Nevertheless, I wanted to explicitly highlight the obstacles one is likely to meet when starting from this platform. They include not only those specific to the Web, but also issues that occur far more widely (e.g. monopoly ontologies.) I showed how, in the short-term, we can overcome these with solutions intended to be domain-appropriate to their use (within the syntactic limits of JavaScript).

6.2 What next?

Id/SVG more or less realises my desired substrate for implementing Id. However, there is one major area I failed to make domain-appropriate. Despite representing the "data" parts of the system as I wanted, the *computational* parts of Id were just transplanted into the text boxes as source code. I will reiterate that this is *sometimes* suitable, but not always, and it would be worth exploring alternative ways to express some of it in the substrate I have. Having JavaScript code that the user can modify also seems to mess up the browser's debugger when stepping through it.

Still, in this mostly-suitable substrate for Id, I can continue with my project of seeing whether the *allure* of [Piu06] can be saved from the text-based "hidden world" limitation that pervades it. The obvious next step is attempting "self-implementation". This is desirable is because I still have not escaped my text editor. Any changes to my Id/SVG substrate (of nested box drawing) require going back to the script files; I still cannot take advantage of the system I have developed, to ease its own development. In the words of [Piu06], I wish to make it so that the original JavaScript files can be "jettisoned without remorse".

In Section 3.1, I touched on how everyone with a browser has access to a powerful vector graphics editor (SVG) locked behind a completely inappropriate UI (the JS Console). It is similar for 3D graphics (WebGL), and sound and music (Web Audio). Similar observations are made about "native" OS apps in [Hag13]. Unfortunately for that domain, the interface that unlocks your operating system's range of functionalities—batch-mode compilation—is quite far from the affordances of the (interactive) JS Console.

I hope to use Id/SVG to "tame" SVG and other JavaScript APIs, with some minimal on-demand visualisation in the large portion of the screen next to the JS console. This is an attempt to generalise the "rect controls", which allow the obvious geometric properties of a <rect> to be directly manipulated (Section 4.4). Giving Id access to Web technologies in this way is essential for evolving it into a *fully-featured* self-changeable software environment, which could allow as much domain-specifc representation as its user wishes.

References

[Bas+16] Antranig Basman, Luke Church, Clemens Klokmose, and Colin Clark. *Software and How it Lives On — Embedding Live Programs in the World Around Them*. 2016. URL: http://www.klokmose.net/clemens/wp-content/uploads/2016/10/ppig-2016.pdf.

[Bas18] Antranig Basman. “Critique of ‘Semprola: A Semiotic Programming Language’”. In: *Conference Companion of the 2nd International Conference on Art, Science, and Engineering of Programming*. Programming’18 Companion. Nice, France, 2018, pages 214–217. ISBN: 9781450355131. DOI: 10.1145/3191697.3214331. URL: https://doi.org/10.1145/3191697.3214331.

[Bor+97] Alan Borning, Kim Marriott, Peter Stuckey, and Yi Xiao. “Solving Linear Arithmetic Constraints for User Interface Applications”. In: *Proceedings of the 1997 ACM Symposium on User Interface Software and Technology* (1997), pages 87–96. URL: https://constraints.cs.washington.edu/solvers/uist97.html.

[dA86] Andrea diSessa and Harold Abelson. *Boxer: a reconstructible computational medium*. 1986. URL: http://worrydream.com/refs/diSessa%20-%20Boxer%20-%20A%20Reconstructible%20Computational%20Medium.pdf.

[Hag10] James Hague. *Living Inside Your Own Black Box*. 2010. URL: https://prog21.dadgum.com/66.html.

[Hag13] James Hague. *Dynamic Everything Else*. 2013. URL: https://prog21.dadgum.com/182.html.

[Jak18] Joel Jakubovic. *Hacking together OROM/DOM+Ctrl+Shift+J*. 2018. URL: https://programmingmadecomplicated.wordpress.com/2018/01/18/3-hacking-together-orom-domctrlshiftj/.

[Kel17] Stephen Kell. *Some Were Meant for C: The Endurance of an Unmanageable Language*. 2017. URL: https://www.cs.kent.ac.uk/people/staff/srk21/research/papers/kell17some-preprint.pdf.

[Piu06] Ian Piumarta. *Accessible Language-Based Environments of Recursive Theories*. 2006. URL: http://www.vpri.org/pdf/rn2006001a_colaswp.pdf.

[PW06] Ian Piumarta and Alessandro Warth. *Open, Reusable Object Models*. 2006. URL: http://www.vpri.org/pdf/tr2006003a_objmod.pdf.

[Sha18] Oli Sharpe. *Semprola: a semiotic programming language*. 2018. URL: https://www.shift-society.org/salon/papers/2018/revised/semprola.pdf.

[SVG11] Working Group SVG. *SVG 1.1 Specification: 9.2 The “rect” Element*. 2011. URL: https://www.w3.org/TR/SVG11/shapes.html#RectElement.