Representation, Inclusion, and Innovation

Multidisciplinary Explorations

Synthesis Lectures on Human-Centered Informatics

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Representation, Inclusion, and Innovation

Multidisciplinary Explorations

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ABSTRACT

A representation is a thing that can be interpreted as providing information about something: a map, or a graph, for example. This book is about the expanding world of computational representations, representations that use the power of computation to provide information in new forms, and in new ways. Unlike printed maps or graphs, computational representations can be dynamic, and even interactive, so that what is represented, and how, can be shaped by user actions. Exploring these new possibilities can be guided by an emerging theory of representation, that clarifies what characteristics representations must have to express the meaning being represented, and to enable users to discern that meaning easily and accurately. The theory also shows the way to inclusive design, for example using sounds to represent information commonly presented visually, so that people who cannot see can understand what is being presented. Because representations must be shaped by the abilities of their users, and by the nature of the meanings they convey, creating them requires perspectives from multiple disciplines, including psychology, as well as computer science, and the sciences appropriate to the content being expressed. The book presents a series of explorations of this large and complicated space, as invitations to further study, and to innovation.

KEYWORDS

representations, inclusive design, visualization, interactive simulations, aesthetics, visual programming

Contents

Preface xiii

1 Theory of Representation 1

1.1 From Theory to Practice: Creating a New Representational System, and Using It 11

1.2 Representations and Inclusive Design 13

2 Interactive Simulation I: Dynamic Electric Field 15

2.1 Interacting with the Simulation 18

2.2 Model and Views 25

3 Interactive Simulation II: Balloons and Static Electricity 27

3.1 Perspective from Theory of Representations 30

4 Amodal Representations for Interactive Simulations 33

5 Non-visual Visual Programming I: Dataflow 43

5.1 Dataflow Programming 43

5.2 Noodle: Non-visual Dataflow 45

5.3 Reflection 47

6 Non-visual Visual Programming II: A Blocks Language 49

6.1 Non-visual Programming Tasks 53

7 Auditory Turtle Graphics 55

7.1 The Myth of Geometry 58

8 Music and Movement: Truslit 61

9 Representing Higher-dimensional Structures 67

9.1 Applying the Raman Principle? 73

10 The Aesthetic Potential of Representations of Algorithms 75

References 87

Author Biography 93

Preface

What characterizes … new media are their unprecedented dynamics, based on their underlying computational mechanisms. …[W]e need the creative elaboration of the particular dynamic capabilities that these new media afford and of the ways that through them humans and machines together can perform interesting new effects. These are avenues that have just begun to be explored, primarily in the fields of new media, graphics and animation, art and design. Not only do these experiments promise innovations in our thinking about machines, but they also open up the equally exciting prospect of new conceptualizations of what it means to be human, understood not as a bounded, rational entity, but as an unfolding, shifting biography of culturally specific experience and relations, inflected for each of us in uniquely particular ways.

–Suchman (2007), p. 23.

Representations are all around us: a map represents a place, a picture can represent a person, a curve drawn on paper can represent a mathematical function, this book represents a collection of ideas. We'll get more technical about just what representations are, and how they work, but for now we'll use examples like these to suggest that a representation is a thing that can be interpreted as providing information *about* something, that is, about whatever is being represented.

The human world has always been full of representations, as far back as we can see, but it's never been fuller than now. That's because of *computation*, whose power is highlighted by Lucy Suchman in the quotation above. The reason computation is so useful, in almost everything that people do, is because of the fabulous resources it offers for new ways of representing things, all kinds of things. These new representations have miraculous advantages over what's been available until now. At the dawn of writing a representation of a few words would be a lump of clay, of substantial size and weight; today, all the books ever published could be fit into a storage device that would fit in your hand; see http://www.gizmodo.co.uk/2016/12/every-book-ever-published-would-fit-on-to-one-hard-disk/. Further, computational representations of books can be sent to the other side of the world with virtually no delay, they can be copied with essentially no delay, and at essentially no cost, and so on.

And we aren't at all limited to representing things like the contents of books. We can create dynamic, animated presentations; what it took the Disney studios weeks to do not long ago can be done today by a schoolchild at their desk. We can create sounds, music, and synthetic speech, all computationally, meaning that these representations share the virtues of lightness, smallness, ease of transmission, and ease of replication of computationally represented text. But more than that, we can control and vary the production of any of these things very easily. A program that creates music won't produce just some particular piece of music, it will let you create the music you want (if you have the patience and skill). And you can interact with the program. It doesn't just produce whatever representation it makes, on its own; it shows you what it is doing and invites you to modify it, while production is going on. An atlas was once a collection of printed maps. If you wanted a different map you had to get a different atlas. Now you can use computational representations that allow you to shape what you want the map to show, and how, with enormous flexibility, and change the view you get as you get it, so as to focus on what you want to see, even if you didn't know what you wanted to see when you started.

Box I.1

The sociologist Bruno Latour, in his essay, "Visualization and Cognition: Thinking with Eyes and Hands" (1986), has described the profound impact of *inscriptions*, things like maps, drawings, diagrams, and tables, on the progress and practice of science. He lists nine properties of such representations that make them especially useful.

They can be *moved* easily from one place to another.

They *don't change* when they are moved.

They are *flat*, and hence content is not hidden.

Their *scale is flexible*, so that structures of very different sizes can be rendered conveniently.

They can be *reproduced* cheaply.

They can be *recombined*, so that information about different things can be brought together. One form of recombination is superimposition.

They can be *made part of a written text*.

They can be analyzed using *two-dimensional geometry*, so that (for example) the sizes of things can be readily measured.

We can see that computational representations intensify some of these benefits; for example, computational representations can be moved and reproduced even more easily than inscriptions on paper, such as Latour studied. Operations like rescaling, recombination, or measurement also become easier and cheaper. But the potential of computational representations goes beyond intensifying the benefits of inscriptions to providing new ones: interactive control, moving images, the integration of sound and image, and much more.

One of the consequences of the enormous new potential of computational representations is to greatly expand the audience for information of all kinds. It used to be that blind people could only read newspapers if someone else read the material and recorded it, or transcribed it as Braille. Today, almost all newspapers provide computational representations of their content that can be presented to anyone as synthetic speech. This is an example of the potential of computational representations to support *inclusive design*, that is, the design of representations that can be processed effectively by the widest audience.

This book is about this expanding world of computational representations, including its potential for inclusive design. I'm writing it because, exciting as what we can now do every day is, there's more that we can do. I also think that the frontiers of what we can do, the new possibilities, are *interesting*, as well as important, and I want to share the excitement I feel about them.

So this book isn't meant to be a report of what I or other people have already done. Rather, it's a report of *explorations*, attempts to push back those frontiers. As you'll see, the explorations are all incomplete, and some are, so far at any rate, failures. Maybe none of them will prove to have mapped territory that people in the future will find especially useful. But I hope to show something of what's out there, and what you will see if you go there yourself. I'm hoping that you'll find more than I have.

When exploring something, it's helpful to have some kind of map, however rough, within which to sketch the new things you find. I've found it helpful to use a theory for this, a *theory of representation*, that is broad enough to encompass the wide range of content and technology with which we will be concerned. As discussed in the next chapter, this theory is built on a substantial mathematical foundation, something called the *representational theory of measurement*. It adds vital insights from the work of Jock Mackinlay, who showed how this kind of theory can expose the key challenges in creating any representation, of anything: *expressiveness*, that is, the ability for a representation to be faithful to the structure of what's being represented, and *effectiveness*, the requirement that the operations that have to be performed to use a representation, for example comparing the lengths of two bars in a bar chart, can be performed easily and accurately by whoever has to perform them. One can see that what's effective for one person won't necessarily be effective for another: someone who can't see the bars can't readily compare their lengths. This is the aspect of the theory that supports inclusive design.

As we've seen, representations today can be highly dynamic, and interactive. I sketch how the theory can be expanded to provide a useful way to think about these kinds of representations, as well as the familiar static ones that sit still on a page or on a screen.

This theory requires ideas from more than one discipline to deploy it, which is to say that ideas from more than one discipline are required to develop new representations. The theory distinguishes two domains, a *target* domain, which is whatever we are actually interested in, for example world affairs, and a *representation* domain, which contains whatever the representation itself is, for example words printed on paper, or synthetic speech. Building new representations requires ideas about both domains. For the representation domain, we may need to know about printing, or (for all the explorations reported here) computer programs, the displays they produce, and how to support possible ways of interacting with them. We also need ideas from the target domain: what is it about world affairs that we care about? What does the representation need to help us do?

The effectiveness requirement brings in even more ideas, quite different ones. If our representations are going to be consumed by people, we need to know what people can do easily, and what they can't. This is psychology. I hope you will enjoy having all these ideas, from different fields, rattling around together.

As we develop this theory we'll see how it relates to ideas that are familiar to many computer scientists and programmers, the separation of presentation from content, and design patterns that separate *models* from *views*. These ideas take advantage of a natural *layering* that appears in many representations: the representation domain for one representation becomes the target domain for another. So a system can contain a model, that represents some content of interest, but cannot directly be observed by a user; a view then represents the model in a way that the user can observe. To be useful, the view has to be effective, in Mackinlay's sense, and the composite of model and view must be expressive, that is, it must faithfully reflect the structure of the underlying content.

All the explorations in the book involve computational representations, and nearly all the chapters include computer programs that illustrate the ideas. The programs can be accessed from http://claytonhalllewis.github.io/bookPage.html. These programs are not finished work, so please don't expect them to be. I am a shocking programmer, and not at all a "software engineer;" that is, the programs are full of things no one should do. I shouldn't have done them, either, but in trying out the ideas, as they developed, I just didn't make the investment I should have to make the programs clear and clean. The programs have hardly been tested at all; as the wise Antranig Basman has suggested, such programs are "not even software." So please don't take any of the programs as exemplary as programs.

One of the many wonderful things about the world we now live in is that programs like these can be provided to you in a form that you can not only play with, but also modify, to try new ideas of your own, or to make improvements. All of them are written in Javascript, and should run for you in Chrome, Firefox, or Safari, with no need for you to install anything on your computer. Most use no code that isn't already in your browser; for the few exceptions I've included copies of the other code in what's available to you. There's nothing exotic. If you are new to Javascript, or for that matter to programming, there are excellent materials online, for example https://developer.mozilla.org/en-US/docs/Learn/Getting_started_with_the_web/JavaScript_basics, if you know how to create a web page, or https://www.w3schools.com/js/ if you do not. The latter site lets you play with the language in your browser without setting up a web page of your own.

The target domains for the representations in the explorations are varied. The explorations in Chapters 2–4 are about physics concepts. The material is drawn from a large collection of interactive simulations for learning physics developed by my colleagues at the University of Colorado, Boulder, and made available online at https://phet.colorado.edu. They key interest here is, how can one make interactive simulations like these work for people who don't see well? The target domain for Chapters 5 and 6 are programs, written in "visual languages" intended to make programming easier for beginners. Here again the challenge is, how can the conceptual benefits of these "visual languages" work for people who can't work with visual material? A popular programming activity for beginners is turtle graphics, a simple way to make a program draw pictures. Chapter 7 explores how turtle graphics might be made to use sounds rather than drawings. Many people feel that music conveys spatial movement to them as they listen. Chapter 8 explores whether this could be developed as a way to convey graphical information in sound. Chapter 9 explores how forms in more than three spatial dimensions might be represented. Such forms are easy to represent mathematically, but most people find that representation difficult to understand. Can we develop representations that are easier to understand? Finally, the target domain for the exploration in Chapter 10 is programs, again, but here the kind of programs that people in the arts sometimes use. Might it be possible to develop representations of programs that have more aesthetic potential than the textual and visual languages that we have today, and that might have other advantages, such as being more directly intelligible? I've not been able to do this, but perhaps you can.

Many people have helped with this work, by contributing ideas and suggestions, or as collaborators on some of the projects. Of course none of them is to blame for the roughness, or downright wrongness, of the ideas and the programs. They include Tamer Amin, Sina Bahram, Antranig Basman, Alan Blackwell, Beat Brogle, Bill Casson, Hunter Ewen, Michael Eisenberg, Noah Finkelstein, Inge Hinterwaldner, Varsha Koushik, Richard Ladner, Owen Lewis, Emily Moore, Steve Pollock, Alex Repenning, Derek Riemer, Ben Shapiro, Taliesin Smith, Andreas Stefik, and Jason White. Frieder Nake kindly provided examples of his work. Prof. Mehul Bhatt of the University of Bremen welcomed me into his research group. The ATLAS Institute at the University of Colorado Boulder supported some of the work. Colin Clark and an anonymous reviewer read the manuscript in draft and made many valuable suggestions.

For the programs that accompany the book I am indebted to the wonderful ecosystem of freely-available code to do all kinds of things, that the web offers us. Of special value are Blockly, a library for creating blocks languages, created by a group led by Neil Fraser of Google; Flocking, a sound processing system created by Colin Clark of OCAD University; and Raphaël, a library that makes SVG graphics much easier, provided by Dmitry Baranovskiy. The Stack Overflow community, both the people who ask questions, and those who answer them, provided enormously helpful information.

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