Web-Browser Rendering Engine

Davin Lin & Daksh Aggarwal
CSC 207, Spring 2020

Goal

Original Goal: *To build a toy web-browser.*

A web-browser's main components are :

- User Interface
- Rendering Engine
- Networking
- JavaScript Interpreter

We began by implementing the Rendering Engine...

Goal

… and soon realized that we need to focus on just the Rendering Engine.

So our modified goal: *To build a toy Rendering Engine.*

The reason we trimmed down our goal to just the Rendering Engine is two-fold:

- Building a Web Browser engine, even the most basic one, was just too unrealistic. For instance, the programming for browsers like Firefox and Google Chrome runs into millions of lines of code.
- The Rendering Engine is by far the most important component of a web browser.

What is a Rendering Engine?

At a basic level the Rendering Engine:

- first parses the HTML code and the accompanying CSS stylesheets provided by the web-page author
- then it applies CSS styling to the HTML
- finally, it calculates the positioning of elements and renders them to the page.

The Rendering Engine converts web-page code to pretty pictures!

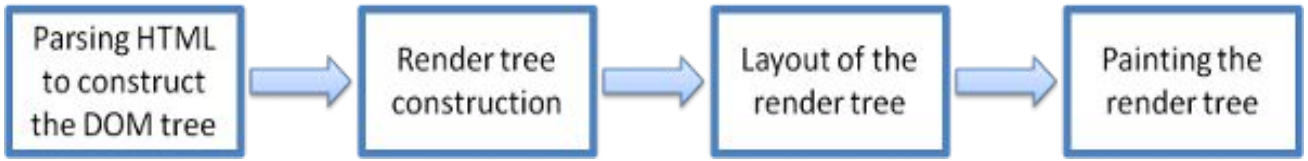
Packages/Libraries

Since we decided to focus on just the Rendering Engine, we have attempted to build an HTML Parser and CSS Parser by hand; so we have avoided using already existing parsers. The main package classes other than the usual ones we employed were for painting images to the screen:

- Java.awt.Font ---> *To Render Text*
- Java.awt.Graphics ----> *To Paint to the Screen*
- Java.awt.image.BufferedImage ----> *To get a Graphics object, since Graphics is abstract*

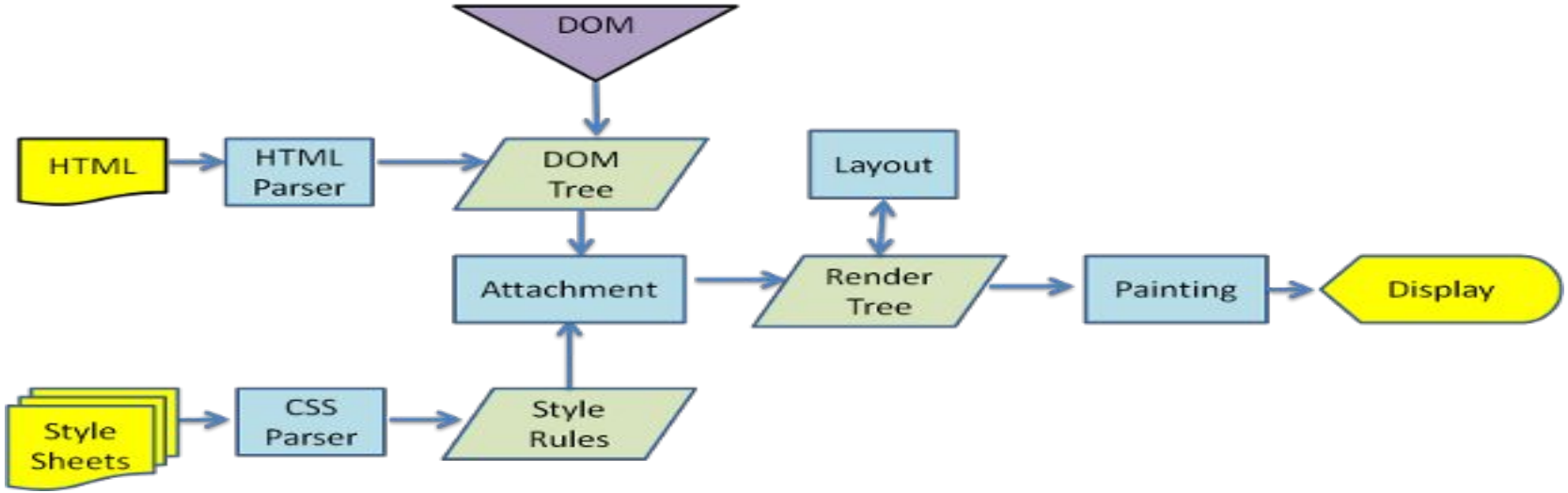
The Rendering Algorithm

The high-level structure of the processing in a Rendering Engine is depicted below:



The Rendering Algorithm

Our implementation follows the same flow used by WebKit, the Rendering Engine underneath the Safari browser:

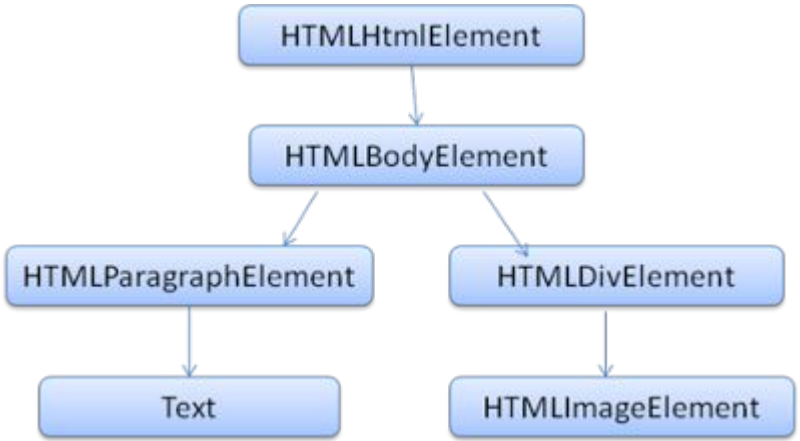


The Rendering Algorithm - DOM

The HTML Parser traverses the provided HTML to produce a **tree,** which is called the **DOM** or **Document Object Model.** An example:

```
<HTML>
    <body>
        <p>
          Hello World
        </p>
        <div><img src = "hello.png"/>
    </body>
</HTML>
```

PARSE



The Rendering Algorithm - DOM

An attentive audience member: “WAIT...”

Davin: “Uh… yeah?”

“Go back a slide!”

“Sure”

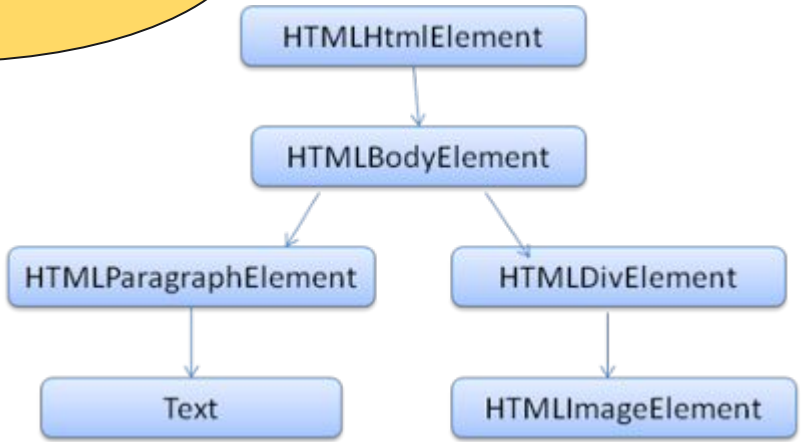
(The dear reader should actually go forward a slide....)

The Rendering Algorithm - DOM

The HTML Parser traverses the pro ch is called the **DOM** or **Document Object Model.** An exa

Why is the closing tag missing??

```
<HTML>
    <body>
        <p>
          Hello World
        </p>
        <div><img src = "hello.png"/>
    </body>
</HTML>
```



The Rendering Algorithm - DOM

Good catch! HTML has a “soft” syntax which allows for such sloppiness.

This is the reason why a full HTML Parser has to necessarily be a large piece of code: it must account for many such allowances that make HTML a user-friendly markup language.

Our implementation however mostly doesn’t allow for such sloppiness and other syntactic sugar, because that would basically involve a lot of hard coding.

The Rendering Algorithm - DOM

The DOM has two different types of nodes:

- **Text node:** This stores the web-page text
- **Element node:** This corresponds to the HTML tags; it has an associated list of children nodes. It also has an associated hash-map which stores the mentioned attributes, such as
  - `img = hello.png`

The Rendering Algorithm - CSS Parser

Next, we parse the CSS into a list of **selectors** and **declarations:**

- A **selector** is a tagname, id, or class name that identifies which HTML elements are to be styled
- A **declaration** specifies the styling that has to be done, such as
  - `font-size : 30 pt;`
  - `background-color : #F08080;`

The Rendering Algorithm - CSS Parser

The CSS specifications also provide for many conveniences for the web-page author (but CSS specs are on the whole more stringent than HTML about correct/valid syntax)

For instance, one can specify `margin-top: 10px; margin-bottom : 20px; margin-right : 30px;margin-left : 40px;` with the single declaration `margin :  10px 20px 30px 40px;`

There are *many* such shorthands and inheritance specifications, but we have included only the most common ones in our implementation.

The Rendering Algorithm - Styled Tree

With the HTML parsed into a DOM and the CSS parsed into a rule list, we merge the two to get the **Styled Tree.**

This is done by finding and collecting the style rules that match each HTML element through a traversal of the DOM to create a **styled node.** While collecting the matching rules, we have to ensure that the more specific rules override the less specific ones.

Further, we have to pass on rules that are supposed to be inherited from the parent node to each child node. For example, the declaration `margin-left:30%` means that the left margin of the element has to be 30% of its parent's left margin. We have to also pass on information about font.

The Rendering Algorithm - Layout

We now process the Styled Tree to specify the positions of each node on the screen, resulting in the **Layout Tree**. This is the trickiest part of the whole rendering process! There are two main reasons:

- The positioning of each element is very much relative to other elements and needs to account for the dimensions specified in the CSS
- Text needs to be laid out carefully, otherwise it will overflow outside its enclosing element or overlap with other text

The Rendering Algorithm - Layout

The Layout Tree mainly contains two types of nodes, which have different processes to determine their positioning:

- **Block Node:** This is an element that will by default extend to fill all the width available in its container. Some examples are `article`,`body`,`h1`,`section` Height of a block node depends on the heights of its children and so has to be determined after laying out the children. Its width can also be constrained using CSS. Finally, the position (x,y) of a block node depends on the position of its parent and the margin, border, etc

The Rendering Algorithm - Layout

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- **Inline Nodes:** These correspond to content such as text and elements which wrap these, such as `em` and `strong`. The width of inline nodes depend on the content they contain. We need to calculate how much space each piece of text will take, and split the text wherever necessary to stay within the parent container. The height depends on the font properties. The position (x,y) is then determined relative to the position of the parent.

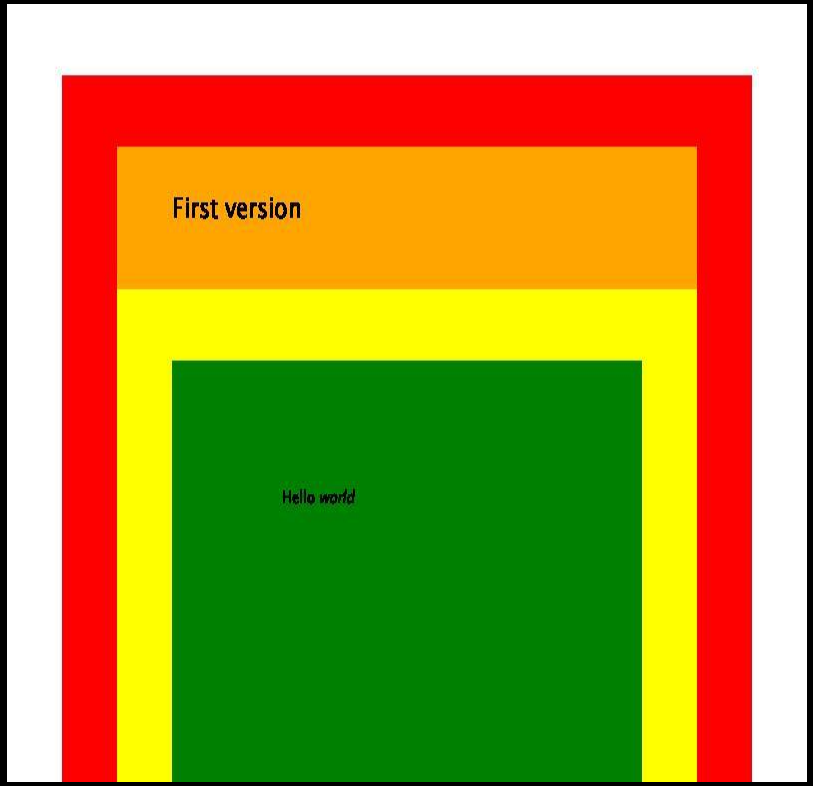
The Rendering Algorithm - Painting

Most of the heavy-lifting has now been done!

We traverse the Layout Tree and extract all displayable elements, which are mainly colored backgrounds, styled text, and images for our Rendering Engine.

Using the Java.awt library we paint to the viewport and produce a .jpg file representing our rendering of the HTML and CSS files we begun with.

Some Examples - Hello World



Some Examples - Professor Paulhus' Homepage

Professor Jennifer Paulhus' homepage served as the primary "real-world" test for our rendering engine. It is interesting to see the progression of the rendered web-page as we incrementally improved our program.

Professor Paulhus' homepage: https://paulhus.math.grinnell.edu/index.html

But first let us see how the page is rendered by Google Chrome

Some Examples - Prof Paulhus' Homepage (Chrome)

Jen Paulhus, Ph.D.

Home Research Teaching

*Sometimes it's so hard to find what it is I'm trying to say. People might think you can turn creativity on and off, but its not like that. It just kinda comes out: a mash up of all these things you collect in your mind. You never know when it's gonna happen. But when it does, it's like **magic**. It's just that simple. And it's just that hard.*
-Gwen Stefani

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Current Teaching

- MAT-195: Demystifying Mathematics
- MAT-321: Foundations of Abstract Algebra

Seminars and Conferences

Simons Collaboration on Arithmetic Geometry, Number Theory, and Computation Annual Meeting
New York City, January 9-10, 2020

AMS Special Session on Rational Points on Algebraic Varieties: Theory and Computation
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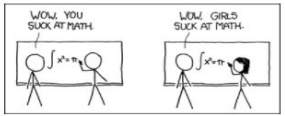
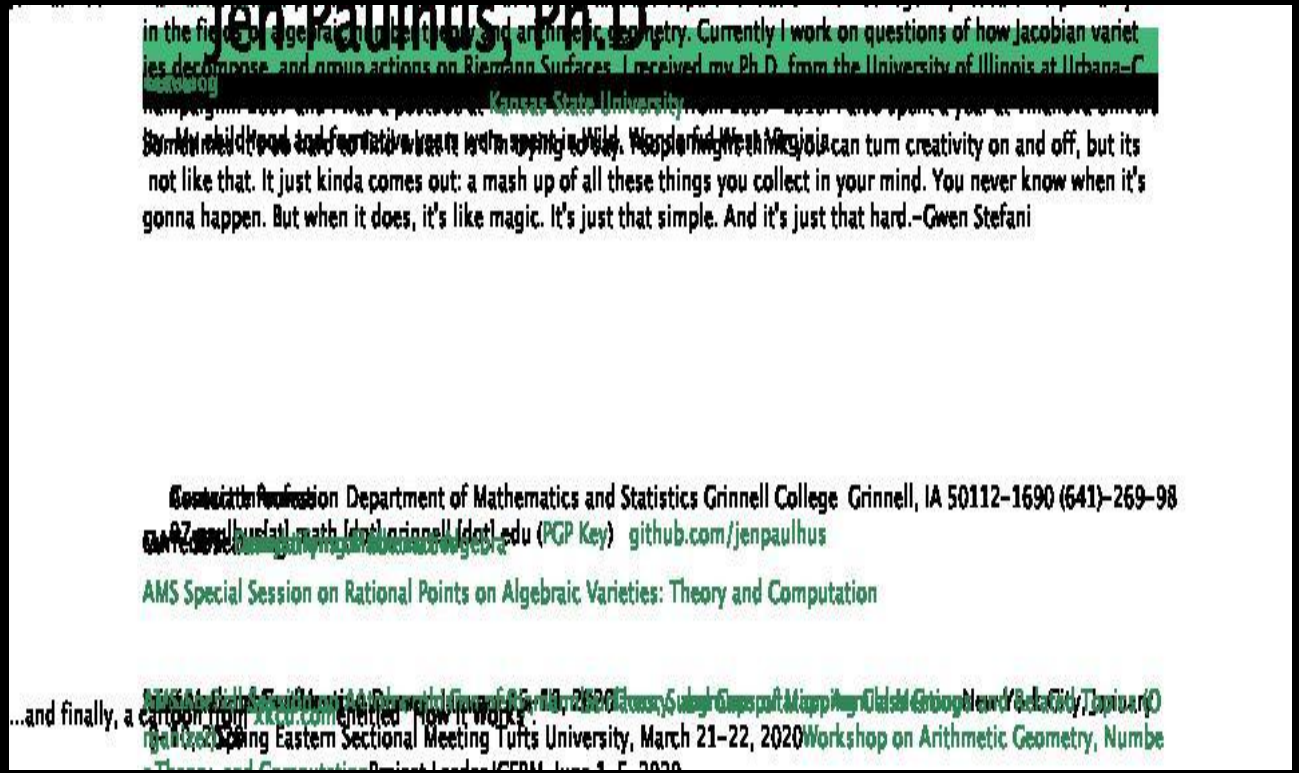
Workshop on Arithmetic Geometry, Number Theory, and Computation
Project Leader
ICERM, June 1-5, 2020

Previous Years

...and finally, a cartoon from xkcd.com entitled "How It Works".



Some Examples - Prof Paulhus' Homepage (v0.1)



Some Examples - Prof Paulhus' Homepage (v0.1)

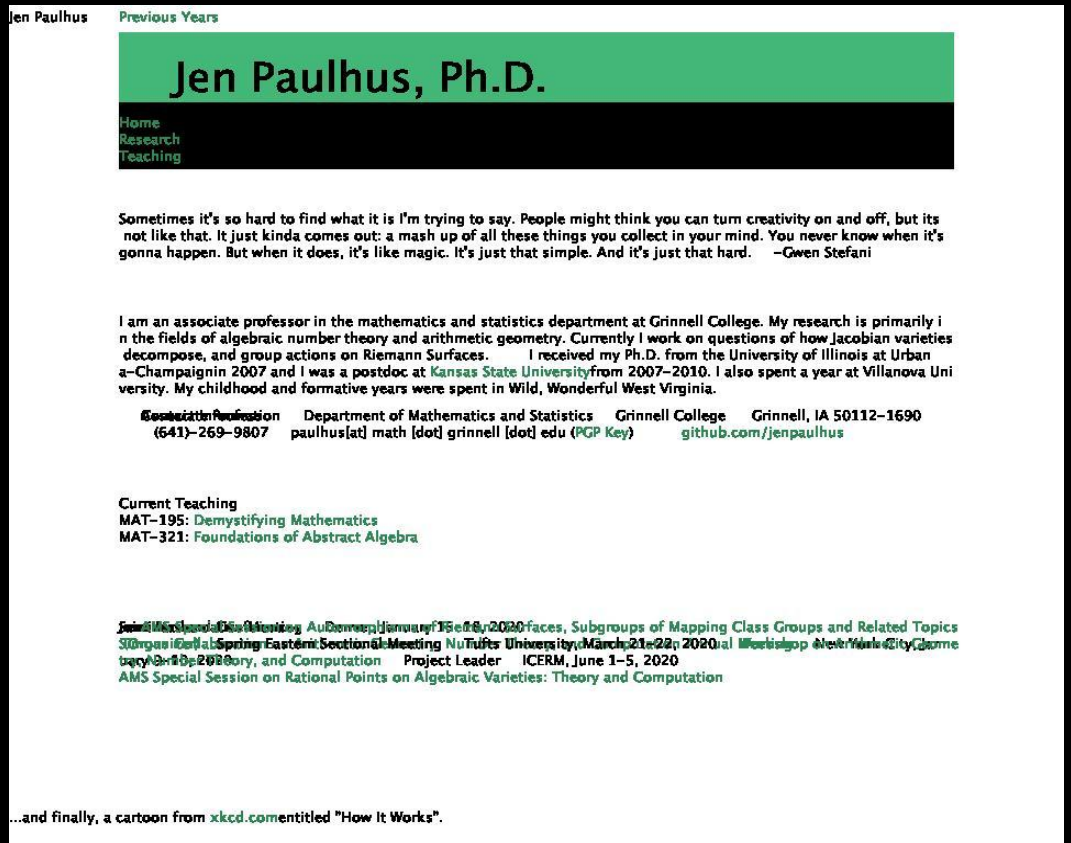
It became clear that our Layout algorithm was not working as expected. So we reimplemented a lot of it.

But getting the layout right at once was difficult

It was a slow incremental process...

Some Examples - Prof Paulhus' Homepage (v1.0)

Much better...



Jen Paulhus Previous Years

Jen Paulhus, Ph.D.

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Sometimes it's so hard to find what it is I'm trying to say. People might think you can turn creativity on and off, but its not like that. It just kinda comes out: a mash up of all these things you collect in your mind. You never know when it's gonna happen. But when it does, it's like magic. It's just that simple. And it's just that hard. –Gwen Stefani

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Current Teaching
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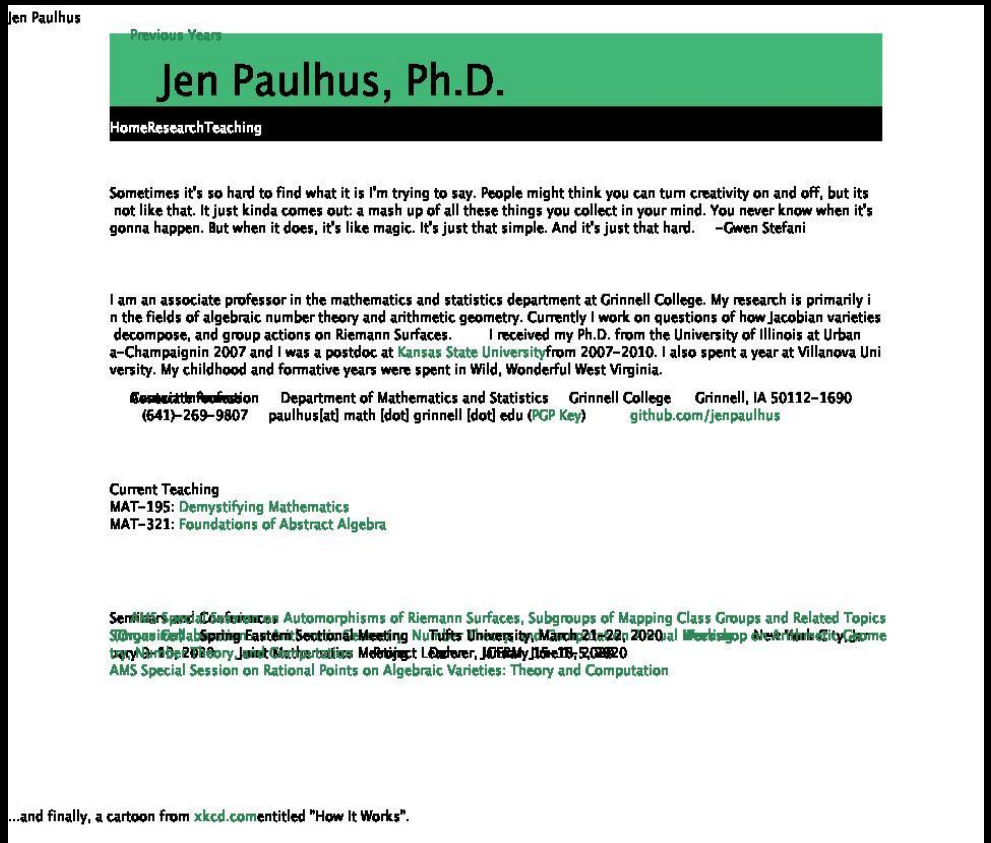
MAT–321: Foundations of Abstract Algebra

Spring Eastern Sectional Meeting Tufts University, March 21–22, 2020
Project Leader ICERM, June 1–5, 2020
AMS Special Session on Rational Points on Algebraic Varieties: Theory and Computation

...and finally, a cartoon from xkcd.comentitled "How It Works".

Some Examples - Prof Paulhus' Homepage (v2.0)

Slightly better…
But text
still flying around



Jen Paulhus

Previous Years

Jen Paulhus, Ph.D.

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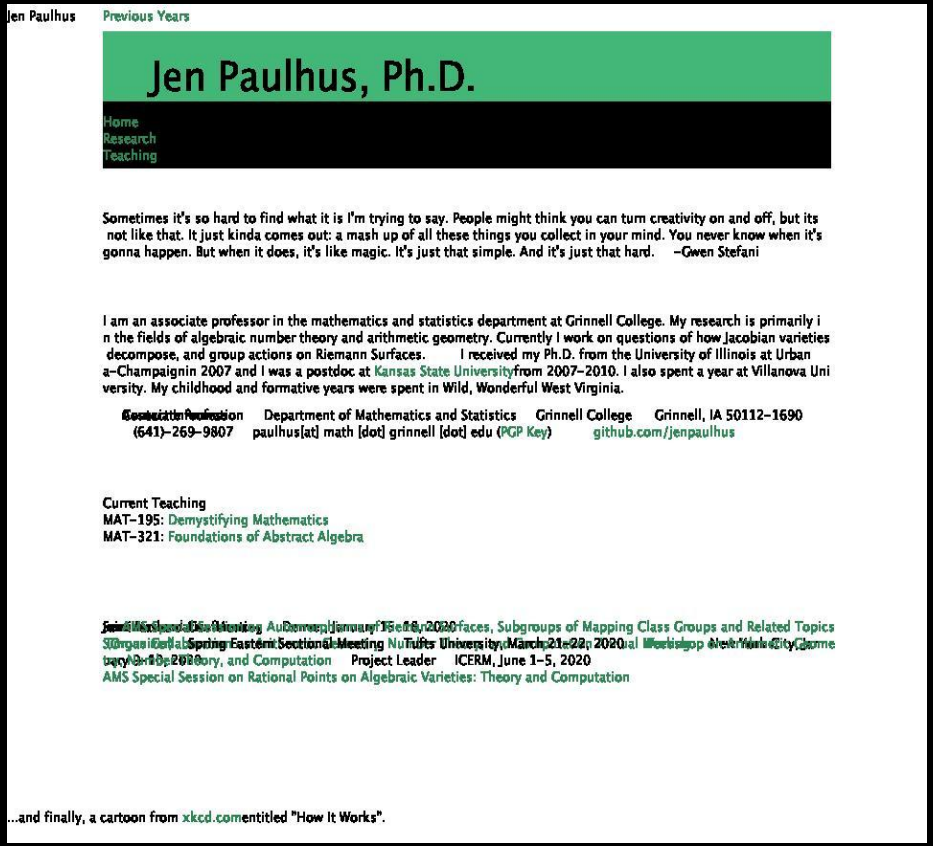
Some Examples - Prof Paulhus' Homepage (v2.5)

Oops, that's worse
Undo!!



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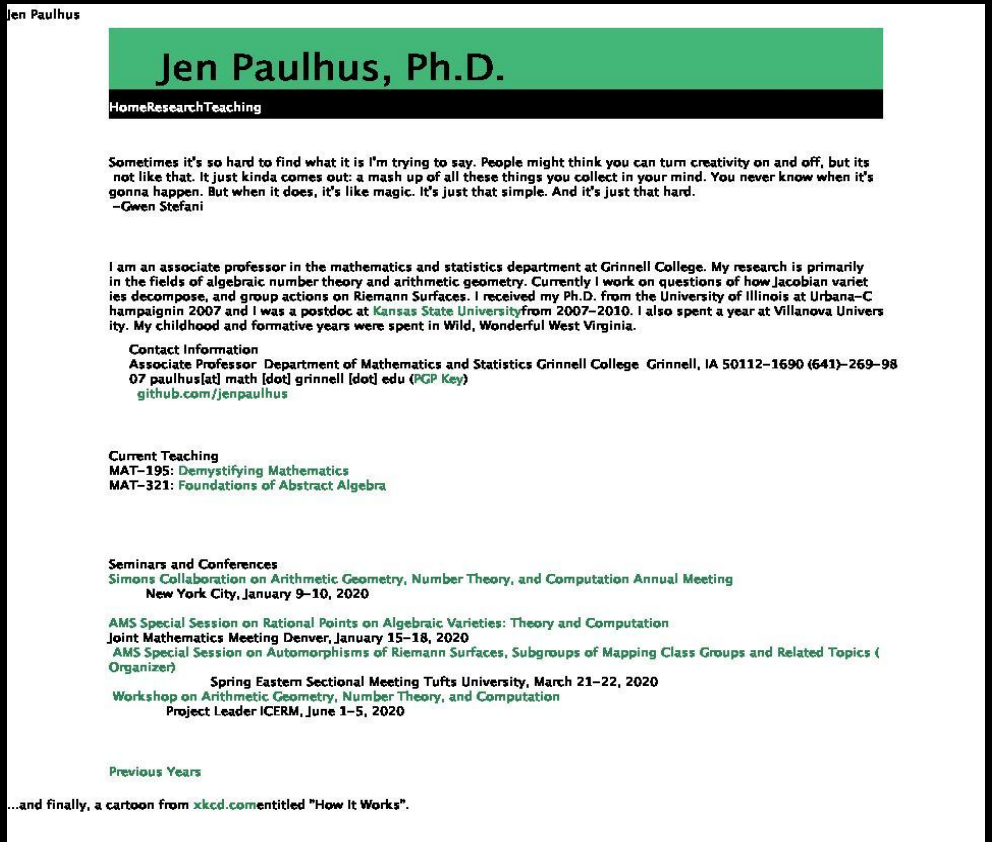
Some Examples - Prof Paulhus' Homepage (v3.0)



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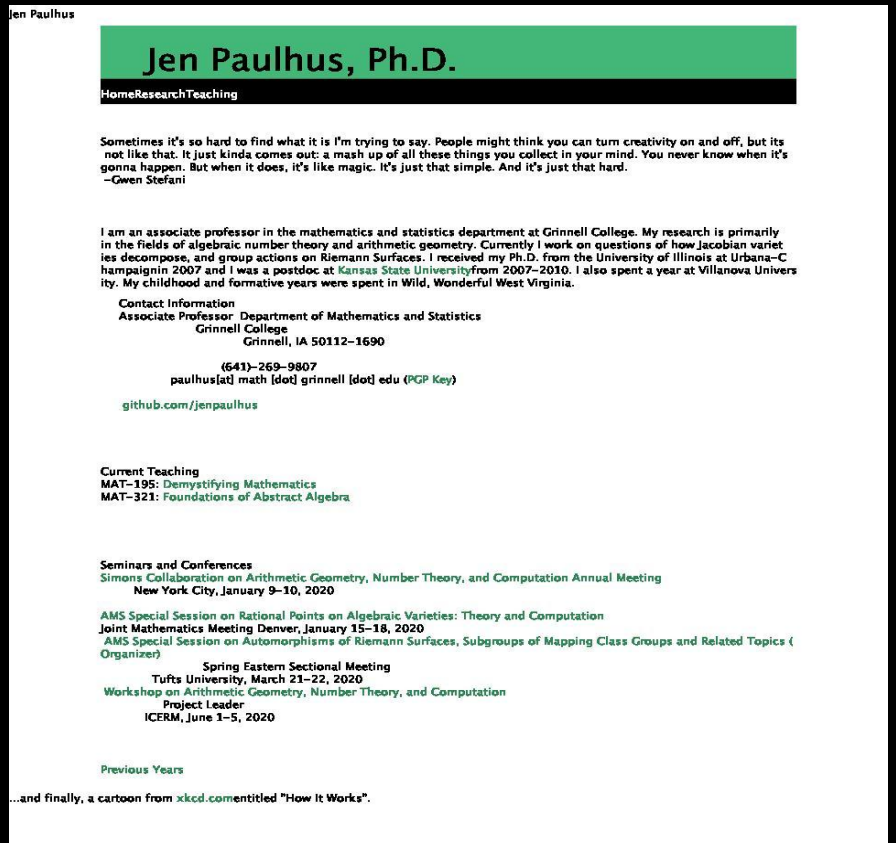
Previous Years

...and finally, a cartoon from xkcd.comentitled "How It Works".

Some Examples - Prof Paulhus' Homepage (v4.0)

Alright, that's not too bad



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Home Research Teaching

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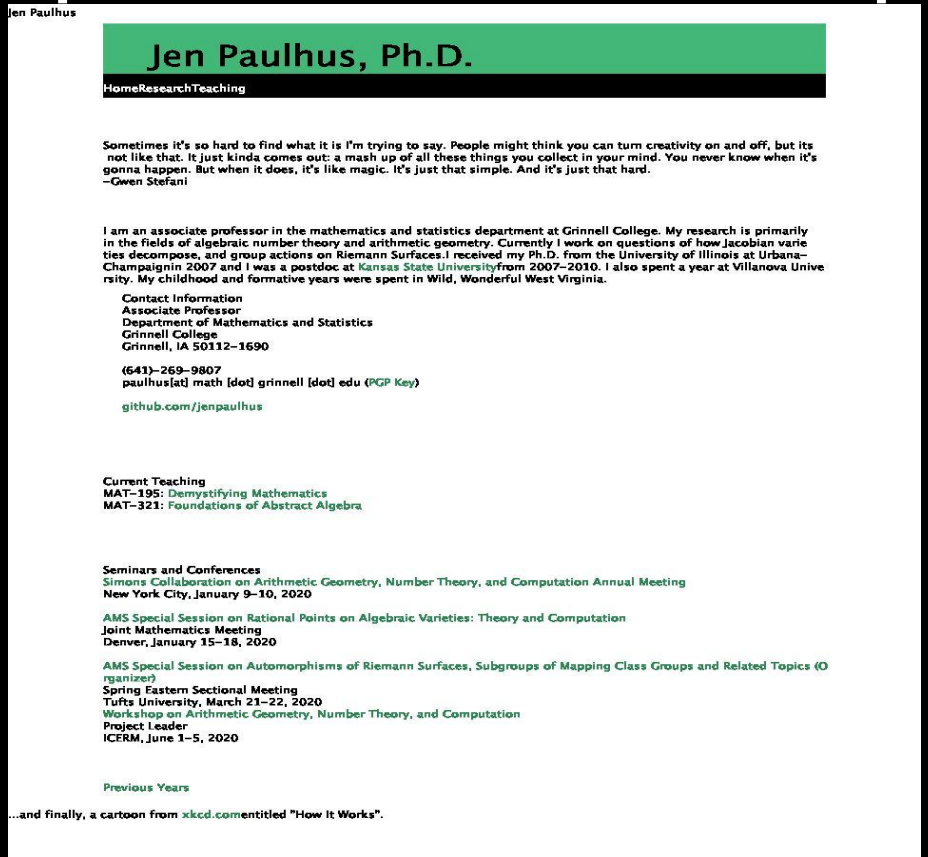
Some Examples - Prof Paulhus' Homepage (v5.0)



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...and finally, a cartoon from xkcd.comentitled "How It Works".

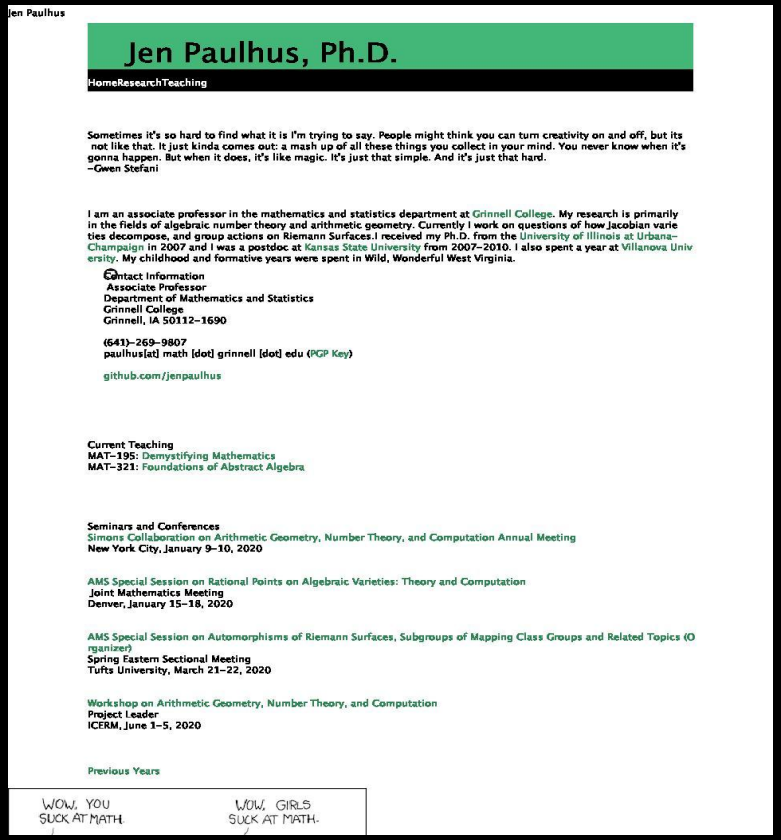
Some Examples - Prof Paulhus' Homepage (v6.0)

Now the layout somewhat resembles the Google Chrome rendering

Next, we tried including images...

Some Examples - Prof Paulhus' Homepage (v6.0)

Image positioning needs to be fixed



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New York City, January 9–10, 2020

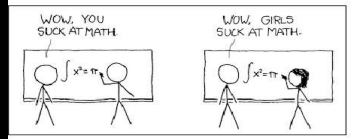
AMS Special Session on Rational Points on Algebraic Varieties: Theory and Computation
Joint Mathematics Meeting
Denver, January 15–18, 2020

AMS Special Session on Automorphisms of Riemann Surfaces, Subgroups of Mapping Class Groups and Related Topics (Organizer)
Spring Eastern Sectional Meeting
Tufts University, March 21–22, 2020

Workshop on Arithmetic Geometry, Number Theory, and Computation
Project Leader
ICERM, June 1–5, 2020

Previous Years

...and finally, a cartoon from xkcd.com entitled "How It Works".



Some Examples - Prof Paulhus' Homepage (v7.0)

Finally, notice that some of our font is missing italics and headings are not of different size.

The reason is because these styles are not specified in the CSS but are rather specified by pre-defined tags in HTML, which browsers have to account for with a default CSS sheet of their own. This is why the same HTML can render differently on different browsers.

After creating our default CSS sheet, we get the current version of our rendering, placed side-by-side with the Google Chrome rendering --->

Some Examples - Prof Paulhus' Homepage (v7.0)

Jen Paulhus, Ph.D.

Home Research Teaching

Sometimes it's so hard to find what it is I'm trying to say. People might think you can turn creativity on and off, but its not like that. It just kinda comes out: a mash up of all these things you collect in your mind. You never know when it's gonna happen. But when it does, it's like **magic**. *It's just that simple. And it's just that hard.*
-Gwen Stefani

I am an associate professor in the mathematics and statistics department at Grinnell College. My research is primarily in the fields of algebraic number theory and arithmetic geometry. Currently I work on questions of how Jacobian varieties decompose, and group actions on Riemann Surfaces.

I received my Ph.D. from the University of Illinois at Urbana-Champaign in 2007 and I was a postdoc at Kansas State University from 2007-2010. I also spent a year at Villanova University. My childhood and formative years were spent in Wild, Wonderful West Virginia.

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Current Teaching

- MAT-195: Demystifying Mathematics
- MAT-321: Foundations of Abstract Algebra

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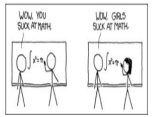

Jen Paulhus

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HomeResearchTeaching

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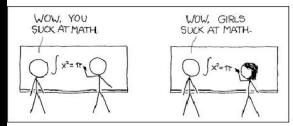

Future Directions

Obviously, there are still many features that our Rendering Engine is missing. Some big possibilities for improvement:

- Increase tolerance of HTML parser to sloppiness; e.g. fill in missing tokens
- Increase ability of CSS parser to parse more types of selectors and also more tolerance to malformed syntax
- Improve processing of layout, it still doesn't properly position inline nodes in some cases; also take into account more kinds of boxes other than Block and Inline
- Improve rendering of font by using a more specialized external Font package
- Support dynamic web-pages

Our Experience

- It was humbling to see and read about the complexity and years of teamwork that go into building a proper rendering engine like WebKit and Gecko, let alone a web-browser like Google Chrome and Firefox.
- We saw that understanding existing implementations is important before trying to directly innovate. E.g., we started by following a simple tutorial[1] by Matt Brubeck, who was part of the Firefox Rendering team, and then added our own features and improvements.
- We also learnt that formal documentation (like CSS specifications) is not as impenetrable as it looks and is much more complete than alternate sources.

[1]Tutorial link: https://limpet.net/mbrubeck/2014/08/08/toy-layout-engine-1.html

References

- Explanatory images in first ten slides taken from: https://www.html5rocks.com/en/tutorials/internals/howbrowserswork/
- Matt Brubeck's Tutorial: https://limpet.net/mbrubeck/2014/08/08/toy-layout-engine-1.html
- CSS Specifications: https://www.w3.org/TR/2011/REC-CSS2-20110607/#minitoc
- Professor Paulhus' homepage: https://paulhus.math.grinnell.edu/index.html