Interactive & Dynamic Force-Directed Graphs with D3

A guided tour through D3 version 4.0 force simulations with dynamic data and user interaction

Robin Weser · Follow
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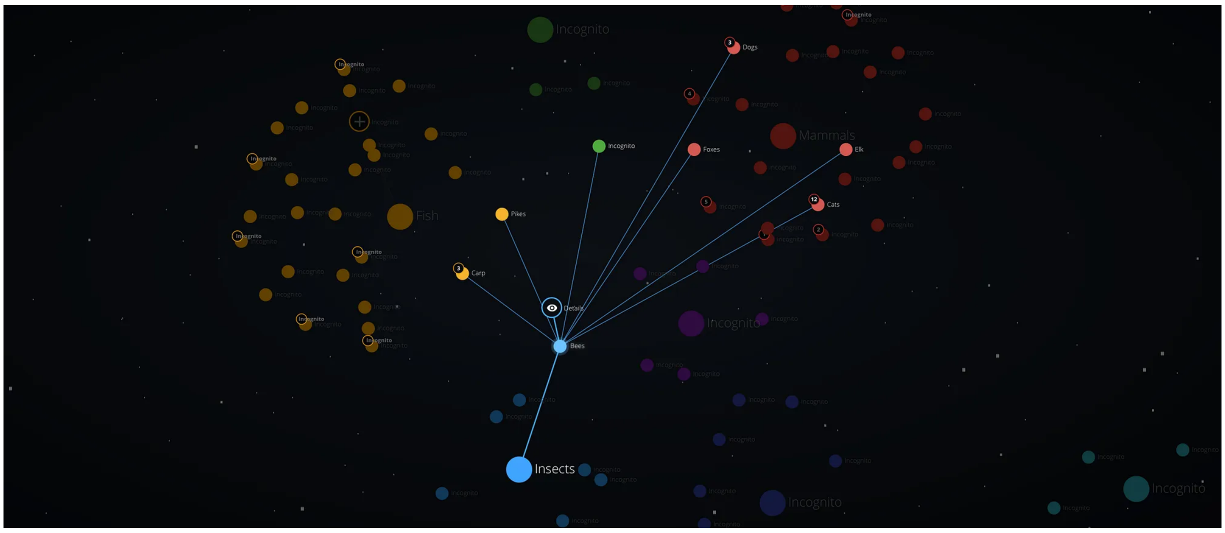


Preview of the final product with a custom "space" design (replaced the real data with mocks)

Many companies have a tremendous amount of data which is not just hard to maintain and manage, but also hard to understand and analyse.

Here, data visualisation should find a remedy. The main goal is to communicate information clearly and efficiently which improves the overall experience.

In this post, I want to explain how we, at NinjaConcept, used D3 to create an interactive and dynamic force-directed graph which helped us to display nested data with complex relations in a simple natural way.

Background

Before we start, I want to explain which requirements we had to fulfill. This might help to understand our decisions better.

Requirements

First of all, the data we had to display was composed of both specially prepared data as well as extractions of the companies long-standing knowledge management system(s).
The hardware requirement was very interesting, too. The graph would have to be build primarily for the new Microsoft Surface Hub, which had a lot of fun playing with. Though, the exiting part was to create a touch-focused interactive app that leverages the advantage of the multi-touch device.

> *Fun fact: We had been able to track up to 13 different fingers at once! Great work, Microsoft.*

Why D3?

As soon as we knew all of the customers requirements, we had to think about which technologies we would use to build the application. After several research and comparison, we chose to use React as our primary user interface library which we would later integrate with D3 and a Meteor backend to serve all the data and other services.

We chose D3 not just because of its popularity and bulletproof core, but especially because of the amazing physical tools provided by d3-force.

Data

D3 is all about (complex) data visualisation. Our goal was to build a force-directed graph similar to this example by D3's creator Mike Bostock himself.
It is based on d3-force and uses the forceSimulation API.

Nodes

Every simulation effectively takes a list of data objects and uses them as **nodes**. Think of those nodes as the data bubbles in the above mentioned example.

For simplicity, we are using a very basic example set of nodes to focus on the implementation. We are using the following list of animals and animal species, where the animals are sub-nodes of the species.

```
[
  { id: "mammal", group: 0, label: "Mammals", level: 1 },
  { id: "dog"   , group: 0, label: "Dogs"   , level: 2 },
  { id: "cat"   , group: 0, label: "Cats"   , level: 2 },
  { id: "fox"   , group: 0, label: "Foxes"  , level: 2 },
  { id: "elk"   , group: 0, label: "Elk"    , level: 2 },
  { id: "insect", group: 1, label: "Insects", level: 1 },
  { id: "ant"   , group: 1, label: "Ants"   , level: 2 },
  { id: "bee"   , group: 1, label: "Bees"   , level: 2 },
  { id: "fish"  , group: 2, label: "Fish"   , level: 1 },
  { id: "carp"  , group: 2, label: "Carp"   , level: 2 },
  { id: "pike"  , group: 2, label: "Pikes"  , level: 2 }
]
```

The key is a unique node id and the level references the level of nesting. The group references one of these groups:

```
{
  0: "mammal",
  1: "insect",
  2: "fish"
}
```

Links

Another important feature of force simulations are links. They connect nodes to display (complex) **relations**. Every link needs to have at least a **source** and a **target**. Both are ids referencing one of the above nodes.

Next to special links, every sub-node *(with level > 1)* is at least linked to its parent node. We are using the following links:

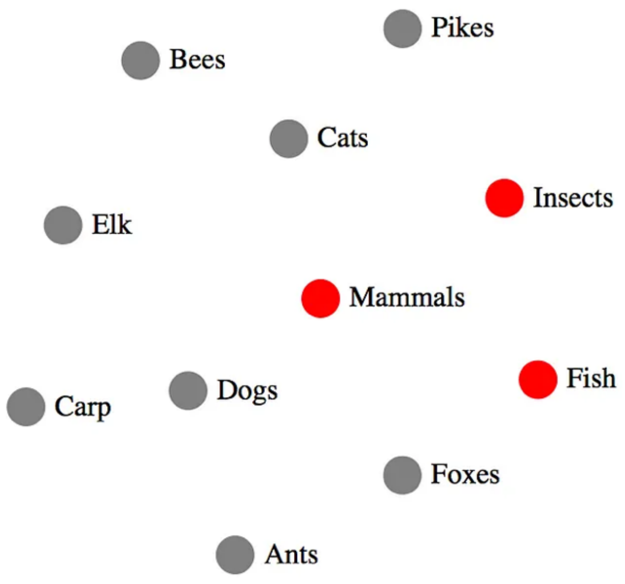
```
[
  { target: "mammal", source: "dog" , strength: 0.7 },
  { target: "mammal", source: "cat" , strength: 0.7 },
  { target: "mammal", source: "fox" , strength: 0.7 },
  { target: "mammal", source: "elk" , strength: 0.7 },
  { target: "insect", source: "ant" , strength: 0.7 },
  { target: "insect", source: "bee" , strength: 0.7 },
  { target: "fish"  , source: "carp", strength: 0.7 },
  { target: "fish"  , source: "pike", strength: 0.7 },

  { target: "cat"   , source: "elk" , strength: 0.1 },
  { target: "carp"  , source: "ant" , strength: 0.1 },
  { target: "elk"   , source: "bee" , strength: 0.1 },
  { target: "dog"   , source: "cat" , strength: 0.1 },
  { target: "fox"   , source: "ant" , strength: 0.1 },
  { target: "pike"  , source: "dog" , strength: 0.1 }
]
```

Implementation

Before we finally start with the implementation, let me describe how we went on. First of all we tried to simply display all the nodes in colored groups. Then we'd add relations (links) and user interaction through touch events. Afterwards we made the whole graph dynamic by default which means adding and removing nodes and links depending on the current selection. Finally, we applied some styling to make the whole graph not only feel great, but actually look great as well.

> ***Disclaimer:*** *The code showed below is written in ECMAScript 2015, although the linked Gists (Bl.ocks) are written in good-old ES5 for compatibility reasons. I will add a full demo including both ES5 and ECMAScript 2015 versions at the end. Cursive words refer to variables or parts of the code itself.*

Displaying Nodes



To start simple, first of all we need to somehow display our data in a force-directed graph using D3. Luckily, this is really straight-forward as we can just take the responsible code snippets from the above mentioned example.

Let's start by selecting a svg element with D3, which will function as a canvas for our graph later. We then set its *width* and *height* to fill the window.

```
const width = window.innerWidth
const height = window.innerHeight

const svg = d3.select('svg')
  .attr('width', width)
  .attr('height', height)
```

Now that we have our container ready, we can create *forceSimulation* instance. We also add two different forces. The first one, ***charge*** is global force that affects **every** node. It simulates electrostatic effects, which makes the graph feel organic and natural as the nodes affect each other. If we'd use a positive *strength*, it'd simulate a gravitational pull.
The second one, ***center***, simply translates all nodes to visually move them into the center of the svg element.

```
const simulation = d3.forceSimulation()
  .force('charge', d3.forceManyBody().strength(-20))
  .force('center', d3.forceCenter(width / 2, height / 2))
```

To draw the *circle* and *text* elements (nodes), we will add two additional *g* elements and use the *nodes*-array as data source. In order to differentiate species from animals, we will use different colors for their respective circles.
Despite to basic attributes such as *r*, *fill* or *font-size*, we also used *dx* and *dy* to relatively position the *text* elements to the right of the *nodes*.

```
function getNodeColor(node) {
  return node.level === 1 ? 'red' : 'gray'
}

const nodeElements = svg.append('g')
  .selectAll('circle')
  .data(nodes)
  .enter().append('circle')
    .attr('r', 10)
    .attr('fill', getNodeColor)

const textElements = svg.append('g')
  .selectAll('text')
  .data(nodes)
```

```
    .enter().append('text')
      .text(node => node.label)
      .attr('font-size', 15)
      .attr('dx', 15)
      .attr('dy', 4)
```

Finally, we need to start the simulation and define a tick functions that is executed on every simulation tick. There, we will basically update the **coordinates** of both *node* and *text* elements.

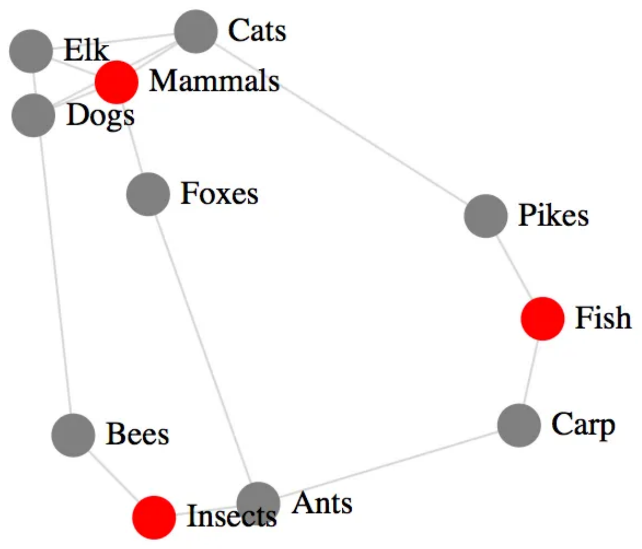
```
simulation.nodes(nodes).on(‘tick’, () => {
  nodeElements
    .attr(“cx”, node => node.x)
    .attr(“cy”, node => node.y)
  textElements
    .attr(“x”, node => node.x)
    .attr(“y”, node => node.y)
})
```

Displaying Nodes

Robin Frischmann's Block 8f88c54b78f16291bdcc5f2df406d6ce

bl.ocks.org

Relations



With our basic data displayed, we now want to show all the relations (links) to understand the connections between the nodes. Links also create forces which either push nodes together or apart depending on the applied strength. This is the point where we make use of the above defined strength for each link: specie-animal relations will have stronger forces to group the nodes tighter together, while cross-relations will pull much softer.

We start by adding the ***link*** force to our simulation.

```
simulation.force('link', d3.forceLink()
  .id(link => link.id)
  .strength(link => link.strength))
```

Then we can create the *line* elements to display our *links* respectively.

This works basically the same as the *circle* and *text* elements as well.

```
const linkElements = svg.append('g')
  .selectAll('line')
  .data(links)
  .enter().append('line')
    .attr('stroke-width', 1)
    .attr('stroke', '#E5E5E5')
```

In order to move the links on every tick, we add the following snippet to the *tick*-function.

```
linkElements
 .attr('x1', link => link.source.x)
 .attr('y1', link => link.source.y)
 .attr('x2', link => link.target.x)
 .attr('y2', link => link.target.y)
```

In a final step we need to apply all *links* to the ***link*** force.

```
simulation.force('link').link(links)
```

Relations

Robin Frischmann's Block ef51753ff4ac2b7d6ebdb04ac182b5c7

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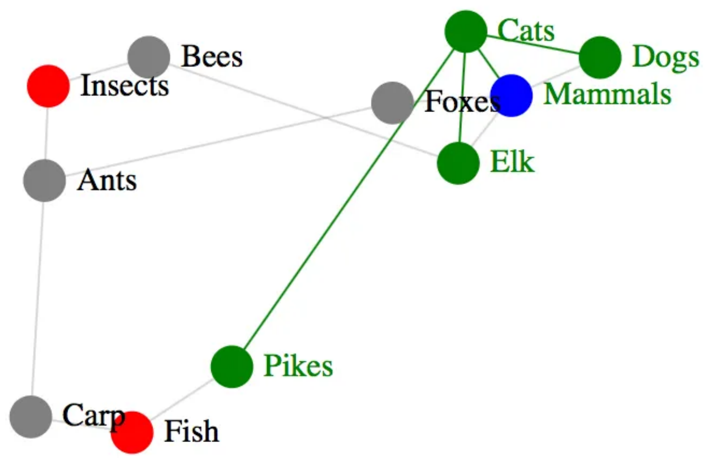
User Interaction



To be able to interact with the graph, we at least need drag & drop. Again, D3 already provides a nice API to add D&D without pain. This was basically copied from the example as well. The *alphaTarget* adjustments help us to create a more natural feeling and to rerun the simulation after the drop.

Drag & Drop

```
const dragDrop = d3.drag()
  .on('start', node => {
    node.fx = node.x
    node.fy = node.y
  })
  .on('drag', node => {
    simulation.alphaTarget(0.7).restart()
    node.fx = d3.event.x
    node.fy = d3.event.y
  })
  .on('end', node => {
    if (!d3.event.active) {
      simulation.alphaTarget(0)
    }
    node.fx = null
    node.fy = null
  })
```

To activate the *dragDrop* events, we only need to add it to the *nodeElements*.

```
nodeElements.call(dragDop)
```

Highlight Selection

Additionally, we wanted to be able to select nodes in order to highlight their relations. To highlight the selection with all its connection we need to know two things.

1. Who are the direct neighbors of the clicked node?
2. Which links connect the clicked node with its neighbors?

This turns out to be very basic. We simply iterate all links and check if either the *target* or the *source* match the *node's* **id**. If yes, we add the counterpart, which then obviously is a direct neighbor. *e.g. If the target.id matches the node.id, we add the source.id to the neighbors-list*. (see *getNeighbors*)

To determine if a link connects the clicked node with one of its neighbors, we basically do the same. A link is a "connection-link" if

either the *target.id* **or** the *source.id* match the *node.id*. (see *isNeighborLink*)

```
function getNeighbors(node) {
  return links.reduce((neighbors, link) => {
    if (link.target.id === node.id) {
      neighbors.push(link.source.id)
    } else if (link.source.id === node.id) {
      neighbors.push(link.target.id)
    }

    return neighbors
  }, [node.id])
}

function isNeighborLink(node, link) {
  return link.target.id === node.id || link.source.id === node.id
}
```

A simple way to visually highlight the nodes and links is by changing their colors. Therefore, we will use the below functions *getTextColor*, *getLinkColor* and *getNodeColor* (which replaces the previous *getNodeColor*). Now, all highlighted animal nodes will be colored green, all specie nodes blue. "connection-links" will be colored in green as well.

```
function getNodeColor(node, neighbors) {
  if (neighbors.indexOf(node.id)) {
    return node.level === 1 ? 'blue' : 'green'
  }
  return node.level === 1 ? 'red' : 'gray'
}

function getTextColor(node, neighbors) {
  return neighbors.indexOf(node.id) ? 'green' : 'black'
}

function getLinkColor(node, link) {
  return isNeighborLink(node, link) ? 'green' : '#E5E5E5'
}
```

Bringing it all together, we have the following *selectNode*-function. It updates the colors of all nodes, texts and links depending on their “neighborhood-status”.

```
function selectNode(selectedNode) {
  const neighbors = getNeighbors(selectedNode)

  nodeElements
    .attr('fill', node => getNodeColor(node, neighbors))
  textElements
    .attr('fill', node => getTextColor(node, neighbors))
  linkElements
    .attr('stroke', link => getLinkColor(selectedNode, link))
}
```

Last but not least, we need to add a **click-event listener** to every node element which calls *selectNode*.

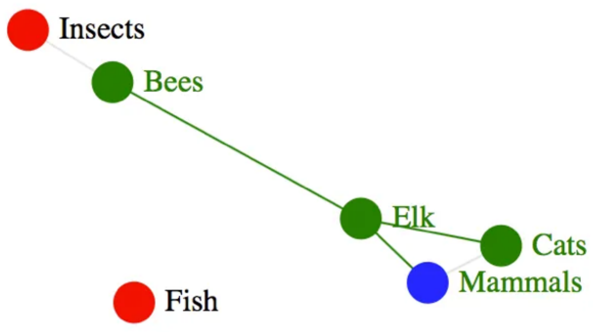
```
nodeElements.on('click', selectNode)
```

User Interaction

Robin Frischmann's Block 74e3b61530c350d1ec1771416249a535

bl.ocks.org

Dynamic Updates



We already have a nice overview of our data, but that is still not enough. Often, data is not something static, but highly dynamic and frequently changes in the course of time. Therefore, we want the graph to update on every change.
Also, with growing data, the graph gets more and more overgrowded and thus confusing and won't feel very user-friendly anymore. By hiding many sub-nodes to only show up when they're effectively required *(e.g. if they have connections to the currently selected node).*

That's why, for both cases, we need the ability to update the graph without a complete reload. Otherwise the simulation would restart and all efforts to ship a user-friendly application would ultimately be destroyed.

Luckily, D3 got us covered (again) with a great example on how to directly modify force-directed graphs. It uses the recommended update pattern, which can be described as: **Mutate > Replace.**

Updating the Data

First of all, we need to mutate our data. As we directly mutate the *nodes* and *links*, we use a copy with all nodes and links for reference. To actually mutate the nodes, we need to know which nodes get removed and which get added. We again use the neighbors to check which nodes to display. The species nodes should always be visible though.

Therefore we are generating a diff. Then, we simply use the diff to add and remove the affected nodes. The same method also applies to the links, although we do not need to mutate them, but can create a whole new array of links as well.

```
function updateData(selectedNode) {
  const neighbors = getNeighbors(selectedNode)

  const newNodes = baseNodes.filter(node => {
    return neighbors.indexOf(node.id) > -1 || node.level === 1
  })

  const diff = {
    removed: nodes.filter(node => newNodes.indexOf(node) === -1),
    added: newNodes.filter(node => nodes.indexOf(node) === -1)
  }

  diff.removed.forEach(node => nodes.splice(nodes.indexOf(node),
1))
  diff.added.forEach(node => nodes.push(node))

  links = baseLinks.filter(link => {
    return link.target.id === selectedNode.id ||
           link.source.id === selectedNode.id
  })
}
```

Updating the Nodes & Links

Now that we have both *nodes* and *links* up-to-date, we need to update the DOM elements to correctly display the new data. D3 will try to reuse existing nodes to only mutate the minimum set of elements. **That the reason why we mutate the data rather than overwriting it.**

We need to modularize the element creation in order to react on updates. Using special svg groups helps us to better group the elements together:

```
const linkGroup = svg.append("g").attr("class", "links")
const nodeGroup = svg.append("g").attr("class", "nodes")
const textGroup = svg.append("g").attr("class", "texts")

let linkElements, nodeElements, textElements
```

Updating existing elements requires to remove old ones and then merge the new ones. Again, D3 has a pretty straightforward pattern to do so.

```
linkElements = linkGroup.selectAll("line").data(links, link => {
  return link.target.id + link.source.id
})

// 1. remove old nodes
linkElements.exit().remove()

// 2. enter and create new ones
const linkEnter = linkElements
  .enter().append("line")
  .attr("stroke-width", 1)
  .attr("stroke", "rgba(50, 50, 50, 0.2)")

// 3. merge
linkElements = linkEnter.merge(linkElements)
```

We will repeat the exact same pattern for both nodes and texts as well and wrap the snippets inside the so-called *updateGraph*-method to later reuse it.

Updating the Simulation

Last but not least, we need to update the simulation to apply the above changes. The following function will update the graph using the above *updateGraph*-method. Afterwards it reinitialises the simulation with the new nodes and links and then restart it.

```
function updateSimulation() {
  updateGraph()

  simulation.nodes.on("tick", /* see above */)
  simulation.force("links")

  simulation.restart()
}
```

To dynamically update the graph depending on the users interaction, we can embed the *updateData* and *updateSimulation*-methods into the *selectNode*-method that is called on every node.

Dynamic Updates

Robin Frischmann's Block 0de01de85296591eb45a1dde2040c5a1

bl.ocks.org

Styling & Visual Design

Now that we have all the logic ready to ship a highly dynamic and interactive graph, we can make it look awesome with basic styling techniques. I will not go into detail here, but just check out the preview at the begining of this posts, to see what's possible without any further tooling and skill.

> ***PS:*** *Some convenient code snippets might have been dropped to keep this post as small and informative as possible. Especially talking about the "Dynamic Updates" part, please refer to the code examples for further information. They also include useful code comments to get along.*

Demo

All code examples are hosted on GitHub. We provide ready-to-run examples wrapped inside a *.html* file directly. Also, there is a code-folder that contains the complete code in modular ES2015 syntax. Check it out: https://github.com/ninjaconcept/d3-force-directed-graph

Conclusion

To keep it short: **Working with D3 is a pleasure.**
We had a lot of fun experimenting with the force simulation API the result is yet quite impressive.

At NinjaConcept, we will definitely use it again soon!

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Written by Robin Weser

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Responses (4)

What are your thoughts? Respond

Petrando Richard
over 6 years ago

Here is an example of interactive family tree build using d3 force layout :

http://scienic-data.com/force-layout-british-monarch-family-tree/

Responsive to cellphone device, altough loding maybe a bit slow.

Still using d3.v3 tough, I still haven't got the time to upgrade it to v4 just yet.

4 Reply

Hideaki Heng Lee
over 7 years ago

Hi Robin, I really love your post and your detailed explanation on the thoughts of how you guys came up this visualization as a solution for the requirements.

I am really interesting to know some details on the Styling & Visual Design part that show on the preview on this page but not the previews from GitHub. I am wondering what are the techniques you used to create the semi blackout for the rest of the nodes that are not linked?

Thanks mate!

Heng

3 1 reply Reply

Florent Georges
about 5 years ago

Broken links

Hi Robin. Great stuff, thank you! Just a quick not that the links to the code blocks do not seem to work anymore. Actually, the Github account **rofrischmann** do not even exist (anymore?)

Are there typos in the links, or did something worse happen in the meantime?

Reply

See all responses

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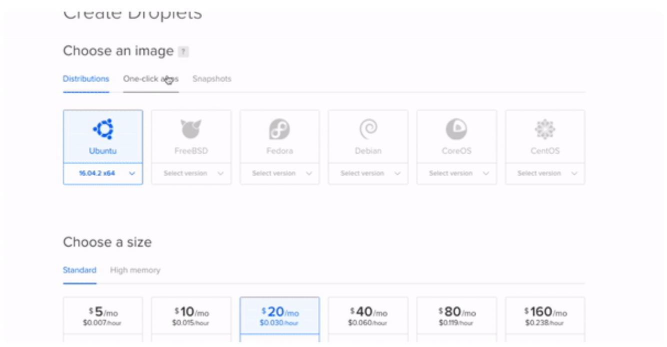

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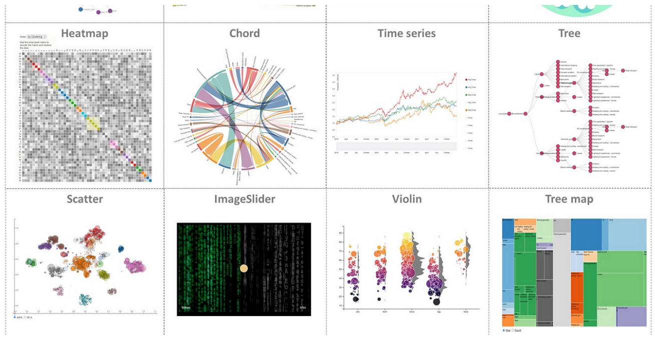

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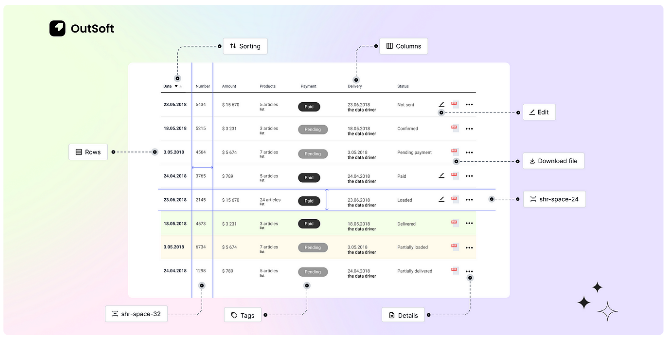

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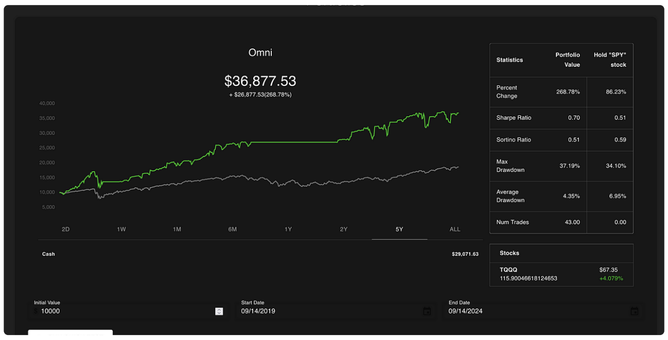

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