DynaMo - Dynamic 3D Models for the Web

A declarative approach to dynamic and interactive 3D models on the web using x3dom

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ABSTRACT

Animations aid greatly to a presentation of a sophisticated man-made object. With additional interactivity, a user can explore such an object to gain even better understanding. The authoring of such dynamic models is often very resource demanding, as the animations and logic of interaction has to be expressed in an authoring program; often using a programming language. Furthermore, the 3D model and its dynamic capabilities are tightly coupled, which makes it costly to integrate changes of the underlying 3D model - e.g. if a machine part changes.

Contribution and Benefit. We present a novel scheme to define varying states of a 3D model in a decoupled, declarative manner using pattern matching. Furthermore, we demonstrate its capabilities for the web with an open source JavaScript implementation that operates on an x3dom model.

CCS CONCEPTS

• Information systems → Web applications; • Computing methodologies → Computer graphics; Procedural animation;

KEYWORDS

animation, x3dom, declarative

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1 INTRODUCTION

As computers and devices are becoming more powerful with less power consumption, web applications are getting richer and graphically elaborate, often with 3D content. Furthermore, since the advent of the WebVR specification, virtual reality (VR) applications can be experienced in the web browser. Due to their realistic representation, 3D models are a favorable way of illustration, especially in the sales and presentation domain. Furthermore, the presentation or understanding of a scene is even better when the scene is dynamic, i.e. the 3D model varies over time – such as a moving or rotating part of a machine – even more so if the model becomes interactive.

The presentation in the web is only one step in the development of a product, the planning and modeling is done in earlier stages. Product Lifecycle Management (PLM) systems integrate the digital representation of the product development. The web presentation should therefore reuse the information present in PLM systems.

The authoring of dynamic 3D scenes in the browser is often time consuming, as the scene needs to be transformed in a format that is suited for display in the browser; dynamic capabilities and interaction logic needs to be scripted or defined using an authoring system. The resulting web application typically induces a tight coupling between animation and interaction and the 3D scene. There is evidence that tight coupling of code components increases technical debt [MacCormack and Sturtevant 2016]; thus, a tight coupling of 3D scene and dynamic capabilities may introduce elaborate workflows, especially if the model changes, for example when a new variant of a model should be introduced in a web shop; another example is that a model should have several geometric variants when the structure does not change, e.g. a low-poly version for a VR headset with weak display capacity.

Therefore, we propose to model the dynamic capabilities of a 3D scene as a separate declarative description with an accompanying library that simplifies the dynamic modeling process, an overview of the method can be seen in Figure 1. We demonstrate the method by providing an open source implementation that operates on x3dom [Behr et al. 2009], the open and human-readable 3D scene-graph embedded in the HTML DOM which is based on the X3D standard [ISO 19775-1 2013].

Figure 1: A static scene, represented as a hierarchical x3d/x3dom model, is augmented with dynamic changes, described as a declarative description of states using JSON, and a thin application layer that represents the interactive logic. The dynamo.js library performs state application and visual transitioning (animation) between states. The separation of 3D model and dynamic properties enables better authoring loops due to an easy replacement or outside modification of the underlying 3D scene.

2 RELATED WORK

The classical approach to dynamic content creation stems from traditional hand-drawn animation: a set of *key frames* is associated to specific points in the timeline, and intermediate frames are generated between two key frames, which is called *inbetweening*, or *tweening* [Kort 2002].

The proposed system builds on the aforementioned technique of key framing and the idea of representing a dynamic system using a graph structure, as is common in the area of character animation: graph based motion synthesis [Arikan and Forsyth 2002], [Kovar et al. 2002], [Lee et al. 2002]. Similar to such systems we allow a set of arbitrary states and transitions between them. Additionally, the system uses pattern matching to identify scene graph nodes to which the animation will be applied, similar to Cascading Style Sheets (CSS). While x3dom [Behr et al. 2009] and other methods [Seo et al. 2017] utilize CSS to define 3D transformations, it does not allow the aggregation of several animations at once to the same attribute of a Document Object Model (DOM) element.

Our solution was motivated by a practical example: creating an interactive model of an existing representation from a PLM system. The industry standard for exchange data of such systems is the ISO STEP Standard which stands for “Standard for the Exchange of Product model data” [ISO 10303-242 2014]. We utilized pythonOCC, a python binding to the OpenCascade modeling kernel, to convert the STEP representation to X3D [Paviot 2018].

There exists a large amount of software that allows to author interactive scenes, e.g. game engines that also deploy to the web browser, such as Unity3D [Unity Technologies 2018]; Blend4Web [Blend4web 2018] is a plug-in for the open source modeling suite Blender [Foundation 2018] that allows to export interactive 3D content to the web browser. To our knowledge the use of such engines always introduces tight coupling between application logic and the 3D scene.

Thus, we build upon the open x3dom system to represent dynamic scenes in the web. x3dom also offers dynamic capabilities [Behr et al. 2011]: dynamic content can be added to the scene graph using time sensors, routes and interpolation nodes to modify content.

There exist also domain-specific extensions to x3d/x3dom, utilizing a more abstract scene definition, for example the extensions for animation control of humanoid modeling [Jung and Behr 2008]. Our declarative dynamic description is not intended to replace these mechanisms on implementation level, but to serve as a more convenient and decoupled description of dynamic content – especially for authoring.

3 DYNAMIC MODELS

We define a dynamic model as a 3D model that is composed of several parts with dynamically varying properties, e.g. transformation or color. In Computer Aided Engineering (CAE) and Computer Aided Design (CAD), the abstract representation of a complex model consists of a tree or forest-like data structure that models hierarchical relationships from the whole model down to the parts that the model is composed of, e.g. bolts and screws.

Systems for the visualization of dynamic content also often use a hierarchical representation of a scene called the *scene graph*, that represents the hierarchy of a dynamic scene. The leaves of such a scene graph contain visible elements that represent the smallest possible unit of change of the scene. The scene can be visibly changed by modifying the scene graph and its attributes, e.g. the location of a node. We require a dynamic model to provide support for the following dynamic properties: define varying **state** information and the ability to perform **transitions** from one state to another. State information corresponds to specific properties of a 3D model, e.g. the position of a part. Transitions, i.e. creating several intermediate appearances of the 3D model between states, should be handled automatically.

3.1 A Declarative Description of Model State

As described before, the structure of a 3D model corresponds to a tree like structure. The *state* we want to describe or modify corresponds to attribute values of nodes in this hierarchy. Thus, to describe the state we need to identify the corresponding node(s) and assign values to the attributes. We assume that the input model contains unique labels or other distinguishable meta data for distinct

Figure 2: The system was used to animate parts of a complex model that consists of 499 single parts. Specifying the dynamic behavior using a high level description reduces the complexity to define several animation states using only a handful of matching groups. The animation can be shown using the complete model (left) and only specific parts of the inside that demonstrate the inner workings (right).

parts, as is common in CAD models. We do not want a dependency on the concrete structure, or hierarchy of the CAD model. Thus, we propose to use *pattern matching* on node attributes, e.g. the label, to select desired nodes for state definition. A state definition consists of the attribute name, e.g. translation, and its state value. The value is seen as relative or incremental to any initial state of the attribute in the model. We now group several such match-attribute-value assignments together as a named entity which corresponds to one *named state* of the dynamic model.

3.2 State Value Aggregation

To determine the composite value of each attribute of a named state, all value assignments for one attribute need to be *aggregated*, additionally, an initial value assignment may be defined in the model. Currently, we use a simple heuristic for state value aggregation, dependent on the type of attribute. Translations are simply added, rotations are combined using consecutive application with quaternions, for visibility we chose that *show assignments* override *hide assignments*, etc.

3.3 State Transitions and Animations

In order to animate a model we let the system perform automatic transitions between the states defined in the previous subsection. If the system performs a transition from state *A* to state *B*, it interpolates between the aggregated attribute values of *A* and *B*. The value is used for the transition as a constant when it is defined in *A* only, or a transition between the current model value of that attribute to the definition is made when it is defined in *B* only.

For a state transition, the values relevant attribute consist of booleans or various numerical value types: scalars and vectors. Boolean values or discrete values are switched after half of the transition time, numerical values are linearly interpolated for the transition. Optionally, easing curves may be used to create a visually more appealing transition [Dragicevic et al. 2011]. We define an *animation* to be a (possibly repeating) sequence of arbitrary state transitions. This also implies that distinct animations may share the same states. The graph of possible transitions is implicitly encoded in the application layer, which handles all interaction logic. As all state definitions are defined to be incremental, the system also allows to apply several transitions between two states at once, as long as these transitions do not interfere with each other.

4 DYNAMO.JS: AN X3DOM BASED IMPLEMENTATION

We present an implementation of the dynamic model concept described in Section 3 in the browser, building upon JavaScript and x3dom [Behr et al. 2009]. The static model is encoded as an x3dom scene, as x3dom also allows to include X3D files using an inline node, any X3D model may be used as well.

We first define the declarative description of the dynamic capabilities to be a JavaScript Object Notation (JSON) object, called the *DynaSpec*, as shown in Listing 1 of the appendix. The specification of a dynamic model consists of a list of pattern matching groups that identify parts of the scene, and a number of named states that consist of a list of attribute-value assignments for scene graph nodes or pattern match node groups. Animations are sequences of state transitions. The implementation is a small JavaScript library called *dynamo.js*, it defines the *DynamoInstance* class, each instance of this class is bound to an x3dom canvas, and operates on the x3dom scene of this canvas. The core functionality of the *DynamoInstance* is built upon the following interface:

- constructor** upon initialization, the *DynamoInstance* object is bound to a specific x3dom canvas on which it will perform dynamic state application.
- setState** this method immediately applies all state information that has been associated to the named state that is given as parameter
- doStateTransition** this method immediately performs a transition between two given named states, in the specified amount of time
- enable/disableAnimation** enables or disables the specified animation

4.1 Implementation Notes

For efficiency reasons, the system performs the group matching in a preprocessing step. It traverses the scene graph and collects matching nodes, and initial attribute values for assignments. A node matches if the corresponding DOM node id or X3D DEF name matches the given regular expression; alternatively, an arbitrary attribute can be specified for matching.

After all matching nodes of all groups have been collected, the aggregated attribute values are precalculated for each state. Thus, transition values between states can be calculated efficiently from

these pre-aggregated values. The system allows for enabling or disabling animations, which may be one-shot or cyclic, and launch arbitrary transitions between two states or enable/set any desired state definition using the `dynamo.js` API. The system also allows for asynchronous event registration by registering callbacks for state change or transition finishing events.

4.2 A Real World Example

The proposed system was motivated by a task that involved the presentation and description of a complex machine that creates plastic parts using injection moulding. The 3D model of the machine was given as a STEP export; it consists of 581 nodes, and a total of 499 single shapes instances, of which 186 are distinct base shapes. On the top level, it consists of 62 composite parts that are used to define dynamic behavior.

The CAD model was converted to X3D using `pythonOCC`, the application was written as an `x3dom` html file that includes the X3D model using an inline node. The animation of the machine involves moving two groups of parts apart from each other, and a cogwheel mechanism to move internal parts of the machine. Furthermore, the interactive model should provide a mechanism to hide outer machine parts, so the cogwheel mechanism can be inspected. Using the proposed system, we modeled this behavior using an animation that models the machine functionality with 6 states, and define two additional states that model the visibility state of showing all parts or internal parts. The total `dynaspec` file consists of 150 lines of JSON, 6 groups, 1 animation and 8 states.

5 DISCUSSION AND FUTURE WORK

We propose a method for defining dynamic behavior of a 3D scene using human readable, declarative specification that is decoupled from that scene; we show first results for the web using an implementation that is based on `x3dom`.

In contrast to developing animations natively in `x3dom` using time sensors, interpolators and routes, the proposed description describes such behaviour on a higher level and is therefore more convenient to use in an authoring phase where parts of the dynamic behavior naturally changes during the development. Decoupling the declarative specification of dynamic behavior from the implementation also allows to exchange the underlying implementation. For example, the current JavaScript implementation periodically tracks and updates dynamic node attributes. This was sufficient for the larger model described in Section 4.2; if necessary in the future, the implementation could be rewritten to use the existing `x3dom` dynamic mechanics, such as routes and interpolators to support even larger models. We see great potential in extending the functionality to incorporate different methods of aggregation for state values if the necessity arises, as well as better explicit animation graph representation. Furthermore, a method for automatic placement of labels [Götzelmann et al. 2005], [Stein and Décoret 2008] would also aid visual exploration.

In a broader outlook, we picture the methodology to be able to describe dynamic behavior with respect to all kinds of CAD models, and have different deploy targets such as 3D modeling suites as blender, or game engines, and the web.

Some examples and the `dynamo.js` library are publicly available under <https://github.com/FhA-VC/DynaMo>.

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REFERENCES

- Okan Arikan and David A. Forsyth. 2002. Interactive Motion Generation from Examples. *ACM Trans. Graph.* 21, 3 (July 2002), 483–490. <https://doi.org/10.1145/566654.566606>
- Johannes Behr, Peter Eschler, Yvonne Jung, and Michael Zöllner. 2009. X3DOM: A DOM-based HTML5/X3D Integration Model. In *Proceedings of the 14th International Conference on 3D Web Technology (Web3D '09)*. ACM, New York, NY, USA, 127–135. <https://doi.org/10.1145/1559764.1559784>
- Johannes Behr, Yvonne Jung, Timm Drevensek, and Andreas Aderhold. 2011. Dynamic and Interactive Aspects of X3DOM. In *Proceedings of the 16th International Conference on 3D Web Technology (Web3D '11)*. ACM, New York, NY, USA, 81–87. <https://doi.org/10.1145/2010425.2010440>
- Blend4web. 2018. blend4web - Unleashing the Power of 3D Internet. (2018). Retrieved February 13, 2018 from <https://www.blend4web.com/en/>
- Pierre Dragicevic, Anastasia Bezerianos, Waqas Javed, Niklas Elmquist, and Jean-Daniel Fekete. 2011. Temporal Distortion for Animated Transitions. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI '11)*. ACM, New York, NY, USA, 2009–2018. <https://doi.org/10.1145/1978942.1979233>
- Blender Foundation. 2018. blender.org - Home of the Blender project - Free and Open 3D Creation Software. (2018). Retrieved February 13, 2018 from <https://www.blender.org/>
- Timo Götzelmann, Kamran Ali, Knut Hartmann, and Thomas Strothotte. 2005. Form Follows Function: Aesthetic Interactive Labels. In *Proceedings of the First Eurographics Conference on Computational Aesthetics in Graphics, Visualization and Imaging (Computational Aesthetics '05)*. Eurographics Association, Aire-la-Ville, Switzerland, Switzerland, 193–200. <https://doi.org/10.2312/COMPAESTH/COMPAESTH05/193-200>
- ISO 10303-242. 2014. *Industrial automation systems and integration - Product data representation and exchange - Part 242: Application protocol: Managed model-based 3D engineering*. Standard. International Organization for Standardization, Industrial data, Geneva, CH.
- ISO 19775-1. 2013. *Extensible 3D (X3D) - Part 1: Architecture and base components*. Standard. International Organization for Standardization, Computer graphics, image processing and environmental data representation, Geneva, CH.
- Yvonne Jung and Johannes Behr. 2008. Extending H-anim and X3D for Advanced Animation Control. In *Proceedings of the 13th International Symposium on 3D Web Technology (Web3D '08)*. ACM, New York, NY, USA, 57–65. <https://doi.org/10.1145/1394209.1394224>
- Alexander Kort. 2002. Computer Aided Inbetweening. In *Proceedings of the 2Nd International Symposium on Non-photorealistic Animation and Rendering (NPAR '02)*. ACM, New York, NY, USA, 125–132. <https://doi.org/10.1145/508530.508552>
- Lucas Kovar, Michael Gleicher, and Frédéric Pighin. 2002. Motion Graphs. *ACM Trans. Graph.* 21, 3 (July 2002), 473–482. <https://doi.org/10.1145/566654.566605>
- Jehee Lee, Jinxing Chai, Paul S. A. Reitsma, Jessica K. Hodgins, and Nancy S. Pollard. 2002. Interactive Control of Avatars Animated with Human Motion Data. *ACM Trans. Graph.* 21, 3 (July 2002), 491–500. <https://doi.org/10.1145/566654.566607>
- Alan MacCormack and Daniel J. Sturtevant. 2016. Technical debt and system architecture: The impact of coupling on defect-related activity. *Journal of Systems and Software* 120 (2016), 170 – 182. <https://doi.org/10.1016/j.jss.2016.06.007>
- Thomas Paviot. 2018. `pythonOCC`, 3D CAD/CAE/PLM development framework for the Python programming language. (2018). Retrieved February 13, 2018 from <http://www.pythonocc.org/>
- Daeil Seo, Byoungyun Yoo, and Heedong Ko. 2017. Webized 3D Content Streaming System for Autostereoscopic 3D Displays. In *Proceedings of the 22Nd International Conference on 3D Web Technology (Web3D '17)*. ACM, New York, NY, USA, Article 6, 6 pages. <https://doi.org/10.1145/3055624.3075940>
- Thierry Stein and Xavier Décoret. 2008. Dynamic Label Placement for Improved Interactive Exploration. In *Proceedings of the 6th International Symposium on Non-photorealistic Animation and Rendering (NPAR '08)*. ACM, New York, NY, USA, 15–21. <https://doi.org/10.1145/1377980.1377986>
- Unity Technologies. 2018. Unity 3D. (2018). Retrieved February 13, 2018 from <https://unity3d.com/>

6 APPENDIX: DYNAMIC MODEL EXAMPLE

This tutorial consists of a simple but complete example scene with three objects and two example states, to demonstrate the simplicity of the approach. The example can be run in any browser that fulfills the x3dom prerequisites. This example can be directly evaluated using the developer tools that are integrated in common web browsers. See this example html file that defines a simple scene:

Listing 1: Example x3dom scene

```

1  <!DOCTYPE html>
2  <html>
3    <head>
4      <meta charset="utf-8" />
5      <title>DynaMo</title>
6      <script type="text/javascript" src="https://www.x3dom.
7        org/download/x3dom.js"></script>
8      <script type="text/javascript" src="dynamo.js"></script>
9      <link rel="stylesheet" type="text/css" href="https://www
10        .x3dom.org/download/x3dom.css">
11    </head>
12    <body>
13      <div style="width:500px; height:500px; position: sticky;
14        top:0px; left:0px;">
15        <x3d id="x3dscene" width="500" height="500">
16          <scene>
17            <transform id="PART_A">
18              <shape>
19                <appearance>
20                  <material diffuseColor="1 0 0"></material>
21                </appearance>
22                <sphere></sphere>
23              </shape>
24            </transform>
25            <transform id="PART_B" translation="-3 0 0">
26              <shape>
27                <appearance>
28                  <material diffuseColor="0 1 0"></material>
29                </appearance>
30                <cone></cone>
31              </shape>
32            </transform>
33            <transform id="PART_C" translation="3 0 0">
34              <shape>
35                <appearance>
36                  <material diffuseColor="0 0 1"></material>
37                </appearance>
38                <box></box>
39              </shape>
40            </transform>
41          </scene>
42        </x3d>
43      </div><br>
44      <script>
45        // assign dynaspec definition to variable
46        var spec = {
47          "description" : "dynaspec example",
48          "groups" : {
49            "BC" : {
50              "match" : "PART_B|PART_C"
51            }
52          },
53          "states" : {
54            "A" : {
55              "description" : "first example state",
56              "state" : [
57                {
58                  "id" : "PART_A",
59                  "field" : "translation",
60                  "value" : [0,0,0]
61                },
62                {

```

```

63                  "value" : [1,0,0,-1.5707963]
64                }
65              ],
66            },
67            "B" : {
68              "description" : "second example state",
69              "state" : [
70                {
71                  "id" : "PART_A",
72                  "field" : "translation",
73                  "value" : [0,1.0,0]
74                },
75                {
76                  "group" : "BC",
77                  "field" : "rotation",
78                  "value" : [1,0,0,1.5707963/2.0]
79                }
80              ]
81            }
82          },
83          "animations" : {
84            "anim1" : {
85              "title" : "test animation",
86              "sequence" : [
87                { "from" : "A", "to" : "B", "dur" : 1.0 },
88                { "from" : "B", "to" : "A", "dur" : 2.0 }
89              ]
90            }
91          }
92        };
93      </script>
94    </body>
95  </html>

```

In this x3dom scene, three objects are defined. Their names are PART_A (line 14), PART_B (line 22) and PART_C (line 30). Two example states A (line 52) and B (line 67) are defined in the dynaspec JSON object named *spec*. It contains one example group BC (line 47) that matches to scene node labels PART_B or PART_C (line 48), i.e. the group contains both nodes. The states define dynamic translational behavior on the node PART_A (lines 56 and 71) and dynamic rotational behavior on the group BC (lines 61 and 71).

We now perform some steps that trigger dynamic scene changes using JavaScript. The following commands can be copied and pasted into the JavaScript console of the browser, after the foregoing html file has been loaded (and the *spec* variable is initialized). First, we create an instance of the DynaMo object and bind it to the x3dom canvas. The instance parses the *spec* definition and precalculates state value aggregations:

```
var dynamo = new DynaMoInstance("x3dscene", spec);
```

Then, we apply the modifications from a state. This command combines any initial node values and the state definitions contained in state A.

```
dynamo.setState("A");
```

Next, an example of a dynamic scene modification by letting the system perform a transition from state A to state B in one second:

```
dynamo.doStateTransition("A", "B", 1.0);
```

Finally, the command

```
dynamo.enableAnimation("anim1");
```

enables the animation.