ORTHODONTIST EXPERT SYSTEM

The University of Texas at Dallas

CS 6374.001- Computational Logic

Under the supervision of
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A project report submitted
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1. Introduction

A perfect alignment of all the teeth leads to the perfect beautiful smile. The Orthodontists aim at straightening out the distorted alignment of teeth to help their patients get the desired smile. This task of straightening the uneven alignment of teeth involves various steps. The Orthodontist needs to consider various criteria and needs to check that the action taken does not result in adverse effects on other teeth or the patient's health.

In our project, we are trying to code the rules that the Orthodontists must follow to repair the distorted tooth/alignment. We have developed an Orthodontist Expert System, which, on given a set of crooked or wrongly aligned teeth, displays the sequence of steps to be taken to straighten the alignment.

We are using Constraint Logic Programming in Finite Domain to code the rules. We have coded the rules for 6 different movements of a tooth. The 6 movements are Crown Tipping, Root Tipping, Torqueing, Rotation, Translation and Extrusion/Intrusion. When a tooth is distorted, one of these moves can be executed and the tooth can be brought back to the desired alignment.

2. Tooth Movements

There are 6 possible movements for a tooth. They are:

- **Crown Tipping**: This movement involves moving the crown of the tooth. For this project we have considered the crown tipping only along the X axis. That is, we are considering only frontal view. Crown Tipping happens clockwise and anti-clockwise.

- **Root Tipping**: This movement involves moving the root of the tooth. For this project we have considered the root tipping only along the X axis. That is, we are considering only frontal view. Root Tipping happens clockwise and anti-clockwise.

- **Torqueing**: This movement involves tipping the whole tooth, i.e., tipping both crown and root in the same direction, together. For this project we have considered torqueing only along the X axis. That is, we are considering only frontal view. Torqueing happens clockwise and anti-clockwise.

- **Rotation**: This movement involves rotating the tooth clockwise and anti-clockwise. Here the rotation happens in the Z axis view, i.e., transverse view or top view.

- **Translation**: This movement involves moving the entire tooth left, right, backward or forward. Here we consider the movement along the X axis and the Y axis. Left and Right are movements along X axis. Here moving towards mid-line is known as Mesialization and moving away from mid-line is known as Distalization. Forward (towards the tongue),

also known as Lingualization and Backward (away from the tongue), also known as Expansion are movements along Y axis.

- **Extrusion/Intrusion**: This movement involves moving the tooth up and down (outside and inside). Extrusion is moving the tooth upwards and Intrusion is moving the tooth downwards.

3. Representation of tooth

Each tooth has 3 parameters in its representation. They are as below:

- The numbering assigned to the tooth.
- A set of movement values of the tooth at the current position
- Blockage information: A set of values indicating whether it is blocked from its right and left neighbors.

Tooth Numbering:

We have considered a set of 16 teeth for our project. So, each tooth is numbered from 1 to 16.

Movement Values:

The set of movement values are represented as a list of values as follows: [Crown, Root, Torque, Rotate, [TranslateX, TranslateY], Extrude/Intrude]. This list can have values from -10 to 10.

- The value for Crown indicates the value by which the tooth is crown tipped. A value of 0 means that the tooth is not crown tipped by any amount and its crown is aligned correctly. A value of -2 means, the tooth is crown tipped by a value of 2 towards the right (clockwise). A value of 2 means, the tooth is crown tipped by a value of 2 towards the left (anticlockwise).

- The value for Root indicates the value by which the tooth is root tipped. A value of 0 means that the tooth is not root tipped by any amount and its root is aligned correctly. A value of -2 means, the tooth is root tipped by a value of 2 towards the left (clockwise). A value of 2 means, the tooth is root tipped by a value of 2 towards the right (anticlockwise).

- The value for Torque indicates the value by which the tooth is torqued. A value of 0 means that the tooth is not torqued by any amount and its crown and root, both are aligned correctly. A value of -2 means, the tooth is torqued by a value of 2 towards the right (clockwise). A value of 2 means, the tooth is torqued by a value of 2 towards the left (anticlockwise).

- The value for Rotate indicates the value by which the tooth is rotated. A value of 0 means that the tooth is not rotated by any amount and it is aligned at the correct angle. A value of -2 means, the tooth is rotated by a value of 2 in the clockwise direction. A value of 2 means, the tooth is rotated by a value of 2 in the anti-clockwise direction.

- Translation movement can happen along X axis and Y axis. The value for TranslateX indicates the value by which the tooth is translated in X direction. A value of 0 means that the tooth is not translated by any amount and it is in the correct position along the X axis. A value of -2 means, the tooth is translated by a value of 2 towards the left (negative X direction). A value of 2 means, the tooth is translated by a value of 2 towards the right (positive X direction).

- The value for TranslateY indicates the value by which the tooth is translated in Y direction. A value of 0 means, the tooth is not translated by any amount and it is in the correct position along the Y axis. A value of -2 means, the tooth is translated by a value of 2 away from the tongue (negative Y direction - ***Expansion***). A value of 2 means, the tooth is translated by a value of 2 towards the tongue (positive Y direction – ***Lingualization***).

- The value for Extrude/Intrude indicates the value by which the tooth is extruded or intruded. A value of 0 means, the tooth is neither extruded nor intruded and the tooth is at the desired height. A value of -2 means the tooth is intruded by a value of 2. A value of 2 means the tooth is extruded by a value of 2.

Blockage Information:

A pair of binary values indicating whether the tooth is blocked or not. It is represented as follows: [Left, Right]. The parameters Left and Right can have values 0 or 1.

Left: A value of 0 indicates that the tooth is not blocked by its left neighbor. A value of 1 indicates that the tooth is blocked by its left neighbor.

Right: A value of 0 indicates that the tooth is not blocked by its right neighbor. A value of 1 indicates that the tooth is blocked by its right neighbor.

Consider the below representations:

tooth (1, [0, 0, 0, 0, [0, 0], 0], [0, 0]): This means, the tooth number is 1, there are no defects in this tooth and it is not blocked by any tooth/teeth.

tooth(2, [3, 0, 0, 0, [0, 0], 0], [0,0]): This means, the tooth number is 2, it is crown tipped to the right(anti-clockwise) by a value of 3 and it is not blocked by any tooth/teeth.

tooth(7, [0, 0, 0, 0, [-3, 0], 0], [1, 0]): This means, the tooth number is 7, it is translated to the left by a value of 3 and it is blocked by its left neighbor tooth.

though this could not happen as we would be fixing the tooth 7 by moving it to the right, thus it can only be blocked by it's right neighbor as per our assumption?

4. Implementation

For every type of distortion, 1 or more of the above-mentioned movements can be applied on the tooth/teeth to bring the distorted tooth back to the desired position and alignment. There are certain rules or conditions which decide as to which movement is to be executed. For example, if a tooth's crown is tipped wrongly and it is translated in the forward direction then we perform crown tipping in the opposite direction as needed and translate the tooth to the correct position. If a tooth has more than one flaw, then we must use more than one movement. There are many such rules for the movements.

We have coded all rules like these using Constraint Logic Programming in Finite Domain. Also, our Expert System first solves the blocking tooth/teeth and then solves the tooth under consideration. So, when the system finds that a tooth is blocked, it first solves the defects of the blocking neighbor/neighbors. This is attributed to our trivial assumption that if a tooth is blocked by it's neighbor, then both the teeth are disfigured (not at desired position). So, once we correct or fix the blocking neighbors, we can say that they are fixed and now we can perform fixing for the tooth under consideration initially, as it is block-free.

Suppose if the tooth under check is not blocked at all, then the system directly goes ahead to solve this tooth. Here solving the tooth means, solving all the defects(single/multiple) the tooth has. Be it a neighbor or the initial tooth under consideration, the system solves all the defects of the tooth when it is not blocked by any other tooth/teeth.

Our Orthodontist Expert System displays a sequence of actions that need to be taken to model all the teeth in right alignment. It starts this task by solving every distorted tooth. It continues to do so until there are no more distorted teeth.

Assumptions:

- Crown Tipping, Root Tipping and Torqueing can be performed only along frontal plane (along XZ plane).
- Rotation, TranslationY (As we can further assume that if a tooth is dislocated in +ve (or -ve) direction along X axis, it's right (or left) neighbor should not cause a block; but in case of Y axis, we can not state such assumption. We have to ensure that to perform translateY, both of the neighbors must not cause any blocking.) and Extrusion/Intrusion,

Torquing can be performed only when the tooth is not blocked by its neighbor/neighbors.

- For Crown Tipping, Root Tipping and Torqueing we ignore the block on the side where the tooth is already tipped. We just check for the block on the side where it needs to be tipped so as to get it to the desired alignment.

5. Challenges faced

- Representation of tooth was a major challenge we have faced. Tooth representation tells everything about the current condition of the tooth like, whether it is blocked, whether it is distorted, if distorted then what is the distortion.
- The next challenge was to find fixes for the defects of the tooth and linking them with the blockages the tooth has.
- The third challenge was to eliminate the blocks. This was to solve the defects sequentially, i.e., to solve the blocking neighbors first and then the tooth under consideration.
- The final challenge was to accelerate the system's solving strategy. Initially our system was producing the sequence of actions which would solve only one defect for each tooth. But now our system displays a sequence of actions which solves all defects for every distorted tooth.

6. Results

The figures below show the sequence of steps produced by the Expert system for different teeth configurations.

Configuration 1:

Initial teeth alignment: No tooth is crooked.

```
tooth(1,[0, 0, 0, 0, [0, 0], 0], [0, 0]))
tooth(2,[0, 0, 0, 0, [0, 0], 0], [0, 0]))
tooth(3,[0, 0, 0, 0, [0, 0], 0], [0, 0]))
tooth(4,[0, 0, 0, 0, [0, 0], 0], [0, 0]))
tooth(5,[0, 0, 0, 0, [0, 0], 0], [0, 0]))
tooth(6,[0, 0, 0, 0, [0, 0], 0], [0, 0]))
tooth(7,[0, 0, 0, 0, [0, 0], 0], [0, 0]))
tooth(8,[0, 0, 0, 0, [0, 0], 0], [0, 0]))
tooth(9,[0, 0, 0, 0, [0, 0], 0], [0, 0]))
tooth(10,[0, 0, 0, 0, [0, 0], 0], [0, 0])
tooth(11,[0, 0, 0, 0, [0, 0], 0], [0, 0])
tooth(12,[0, 0, 0, 0, [0, 0], 0], [0, 0])
tooth(13,[0, 0, 0, 0, [0, 0], 0], [0, 0])
tooth(14,[0, 0, 0, 0, [0, 0], 0], [0, 0])
tooth(15,[0, 0, 0, 0, [0, 0], 0], [0, 0])
tooth(16,[0, 0, 0, 0, [0, 0], 0], [0, 0])
```

Sequence of actions needed:

```
No need to see the Doctor!
true.
```

Configuration 2:

Initial teeth alignment: 8 independent teeth with defects.

```
tooth(1,[0, 0, 0, 0, [0, 0], 0], [0, 0])),
tooth(2,[0, 0, 0, 0, [0, 0], 0], [0, 0])),
tooth(3,[0, 0, 0, 0, [0, 0], 0], [0, 0])),
tooth(4,[0, 0, 0, 0, [0, 0], 0], [0, 0])),
tooth(5,[0, 0, 0, 0, [-2, 0], 0], [0, 0]))
tooth(6,[0, 0, -1, 0, [0, 0], 0], [0, 0]))
tooth(7,[0, -3, 0, 0, [0, 0], 0], [0, 0]))
tooth(8,[4, 0, 0, 0, [0, 0], 0], [0, 0])),
tooth(9,[0, 0, 0, -2, [0, 0], 0], [0, 0]))
tooth(10,[0, 0, 0, 0, [1, 0], 0], [0, 0]))
tooth(11,[0, 0, 0, 0, [0, -3], 0], [0, 0])
tooth(12,[0, 0, 0, 0, [0, 0], -4], [0, 0])
tooth(13,[0, 0, 0, 0, [0, 0], 0], [0, 0]))
tooth(14,[0, 0, 0, 0, [0, 0], 0], [0, 0]))
tooth(15,[0, 0, 0, 0, [0, 0], 0], [0, 0]))
tooth(16,[0, 0, 0, 0, [0, 0], 0], [0, 0]))
```

Sequence of actions needed:

```
crownTip(8,-4) rootTip(7,3) torque(6,1) rotate(9,2) translateX(10,-1) translateX(5,2)
 translateY(11,3) extrude(12,4)
true.
```

Configuration 3:

Initial teeth alignment: Tooth 4 blocks tooth 5, tooth 5 blocks tooth 6, tooth 6 blocks tooth 7, tooth 7 blocks tooth 8 and tooth 9 blocks tooth 8. Tooth 8 has translation defect. Tooth 11 blocks tooth 12, tooth 13 blocks tooth 12 and tooth 12 is rotated wrongly. Also tooth 5, tooth 6 and tooth 7 have multiple defects.

```
tooth(1,[0, 0, 0, 0, [0, 0], 0], [0, 0])),
tooth(2,[0, 0, 0, 0, [0, 0], 0], [0, 0])),
tooth(3,[0, 0, 0, 0, [0, 0], 0], [0, 0])),

tooth(4,[0, 0, 0, 0, [2, 0], 0], [0, 0])),
tooth(5,[0, 0, 0, 0, [2, 1], 0], [1, 0])),
tooth(6,[0, -1, 0, 0, [2, 2], 0], [1, 0])),
tooth(7,[0, 0, 0, 0, [2, 3], 0], [1, 0])),
tooth(8,[0, 0, 0, 0, [0, 4], 0], [1, 1])),

tooth(9,[0, 0, 0, 0, [-2, 0], 0], [0, 0])),
tooth(10,[0, 0, 0, 0, [0, 0], 0], [0, 0])),

tooth(11,[-3, 0, 0, 0, [0, 0], 0], [0, 0]),
tooth(12,[0, 0, 0, 4, [0, 0], 0], [1, 1])),
tooth(13,[0, -2, 0, 0, [0, 0], 0], [0, 0]),

tooth(14,[0, 0, 0, 0, [0, 0], 0], [0, 0])),
tooth(15,[0, 0, 0, 0, [0, 0], 0], [0, 0])),
tooth(16,[0, 0, 0, 0, [0, 0], 0], [0, 0])),
```

Sequence of actions needed:

```
translateX(4,-2) translateX(5,-2) translateY(5,-1) rootTip(6,1) translateX(6,-2) t
ranslateY(6,-2) translateX(7,-2) translateY(7,-3) translateX(9,2) translateY(8,-4)
 crownTip(11,3) rootTip(13,2) rotate(12,-4)
true.
```

7. Future Work

In the future we are planning to take into consideration the Crown Tipping, Root tipping and torqueing movements in the sagittal view (along Y axis) as well.