Kinematic Variation
Foot Motion and Deformation Across Substrates

CS 137 Assignment #4

1. Dates
   Introduction  Thurs 10/17
   Part A Sketches  Tues 10/22 and Thurs 10/24
   Part B VR Critiques  Tues 10/29 and Thurs 10/31

2. Goals
   1. Use visualization tools to display several variables of data while maintaining legibility, focusing on the anatomical side of the interaction between foot and ground while a human subject walks on different substrates.

3. Readings
   Check out Steve’s slides and the Hatala et al., 2018 paper on the course website.

4. Scientific Background
   Steve’s main interest is on how animals move around. Related to his work with Kevin Hatala on how human footprints are created, Steve is exploring patterns in foot kinematics (motion). Traditionally, motion data has been restricted to humans walking on stiff, rigid ground. What’s happening on deformable substrates where tracks are made? How does substrate affect movement of the foot as a whole and change the shape of its deformable parts?

   Currently, Steve is working with a lot of data on the feet of human subjects walking through different substrates (e.g., solid, firm mud, and wetter muds). As many as 84 small (1.5 mm) metal bead markers attached to the skin of the sole and toes have been imaged with two X-ray systems. Calibration of these videos allows the 3-D coordinates of each point to be animated. These motion data can be related to various kinematic events (heel strike, foot flat, heel off, toe off) and phases (early stance, mid-stance, push-off) within each step

   The changing position of each marker through time offers multiple ways to visualize foot kinematics. For example, the path of each marker can be used to trace out a motion path (imagine you have a light attached to your foot and take a long exposure photograph of a step). How do motion paths vary among markers and among substrates? Alternatively, marker positions could be connected to form a mesh of triangular patches. How do such patches change throughout the step and across substrates? At a finer scale, how do markers within a specific region of the foot (heel, arch, ball, toes) move relative to one another as the foot encounters different substrates and supports body weight? We encourage you to create your own novel representations as well.

   There are several types of data here involving changes in position and shape through time:

     How might you display dynamic changes (speed, events, phase) along a motion path?
     How might two or more motion paths be compared?
     How can moving surface patches be represented and compared?
How might more subtle deformation such as heel compression be visualized?

**Steve’s Theories**
1. Feet move differently on different substrates during the same walking behavior. Steps in soft mud are not just deeper versions of steps on solid ground.
2. Foot deformation (squashing, flattening, spreading, rebounding) varies with ground stiffness. Substrates push back and change foot shape.
3. There are as yet undiscovered relationships among foot motions on deformable substrates—this is all new stuff.

Steve has data that support these theories and is confident in using them as a foundation for several, unanswered, bigger questions.

**Steve’s Big Questions**
1. Are there consistent relationships between the kinematic events/phases and marker path geometry?
2. How does foot motion vary among substrates?
3. How do markers move relative to one another during changes in shape (deformation)?
4. Ultimately, what do foot kinematics tell us about track formation and help interpret the fossil record?

**5. Assignment**
Steve and Kevin struggle with displaying and interpreting layers of variables. How can they get a more holistic understanding of foot kinematics as measured by the relationships among skin markers? Your assignment is to design visualizations to explore patterns in their data. You don’t need to use the actual data; feel free to use plausible fantasy motions roughly based on reality. Using the scientific background PowerPoint, and paper provided by Steve, design a visualization strategy that can achieve some of the following goals:

- Indicate the path of one or more markers or surface patches through space and time
- Display variables along paths or path trajectories
- Summarize variation among substrates and/or markers
- Explore/compare variation in foot motion or deformation
- Make use of the three dimensionality of the YURT (what can’t we do in 2D?)
- Make effective use of visual tools (e.g., color, form, size, context, sequence)

Variables to consider:
- Marker speed (dynamic measurement)
- Patch size (intermarker distances, area) and orientation (or changes in either)
- Kinematic events (heel strike, foot flat, heel off, toe off)
- Kinematic phases (early stance, mid-stance, push-off)
- Substrate type (solid, firm mud, sloppier muds)
- Specific features of path geometry (curvature, loops)

Context to consider for your design:
Where was the original substrate surface (what’s in air or under ground)?
What is the user’s frame of reference (watching the foot, or riding on the foot?)
What are the units of distance, speed, or time?
Is a legend of colors and symbols needed?
Would a time slider be helpful?
What scale is useful for which analysis tasks?
How does the user interact with the data?
Are display layers useful?

5.1 Part A:
Towards the final design goal, you should begin by making sketches showing various approaches to displaying data and volumetric configuration in 4D (three spatial dimensions plus time) keeping in mind what your visualization would look like once executed in the Yurt. The issue of time sequence can be addressed using toggled frames, as a 3D object or image showing all sequential steps at once, or as a combination of both. In both cases, consider providing a graphic context to clarify issues of spatial position and time steps: a grid, bounding
box or scale of some kind. Add a legend or key to explain how the data is displayed, if necessary.

Your model should involve at least four frames which you or an assistant will cycle through in “Wizard of Oz” technique. If your model traces a sequence through time, then the frames can be keyed to a time sequence. If your model shows time sequence in a single image or object, then your frames might show a changing sample or highlight within the data.

For next Tuesday, you should feel free to bring in as many sketches as you like, perhaps comparing different ideas, structures, connections and gradient choices as they occurred to you during your design process.

Choose a specific aspect of Steve’s science, as listed above, for the focus of your project. Study the animations and other materials from his PowerPoint, and then determine a hypothesis for your visualization. As mentioned above, you may concentrate on displaying the kinematic relationships within one foot, a single variable for several steps, or several variables for several steps. You can include as much contextual information as you think is important: anatomical specifics of the foot; specifics of surrounding substrate or forces at play within it; aspects of the overall visual environment such as substrate surface and layers or artificial narrative devices such as a running track, treadmill, landscape elements etc.

Your ultimate concern, however, should be the legibility of your depiction of Steve’s data. Visual extras should enhance, or at least not interfere, with user perception of this data. Consider the role of abstract graphic structure and gradients in providing clarity and precision. You should be ready to explain why your various choices are important and how they relate to the central data variables.

The crit will be in the classroom.

5.2. Part B: Put your design in CavePainting. Consider how a legend for colors and symbols used, user interactivity, and display layers might be efficiently integrated with the experience of virtual space. What is the most effective sequence for you to present your project to the class, to visually communicate the relationship of the feet, and the variables from the data? Remember, this can be a design plan/interface/tool which has the potential to be implemented by a scientist (in this case Steve) and you should approach the scripting of your performance through the senses and priorities of an imagined user.