Dan Morris’s Notes on:
“Precomputing Interactive Dynamic Deformable Scenes” (James & Fatahalian)

- The big picture
  - I want to apply forces to a deformable model in real-time, but that’s hard.
  - If I can assume that only a limited set of forces will be applied to my model, you can do all your dynamic / deformable simulation offline, and play back your pre-computed simulations at interactive rates.

- I want to use this method to simulate a deformable scene. What do I do?
  - Get models for my scene from 3dcafe.com
  - Choose a small (<10) set of fundamental excitations (forces) my model might be subject to when I play with it in real-time. These are very model-specific entities that a user always has to pick by hand, e.g. “the only way the dinosaur gets moved is via someone poking his three feet”.
    - An excitation has four parameters that I need to specify:
      - An impulse (instantaneous force) \( \alpha^I \)
      - A constant force that persists after the initial force is applied \( \alpha^F \)
      - The amount of time this impulse should be modeled for \( T \)
    - An excitation includes a force at every vertex in my model, even though it might be zero at most vertices. In other words, \( \alpha^I \) and \( \alpha^F \) are vectors.
  - Download my favorite finite element simulator (or some other simulator), and give it my model.
  - Randomly apply the excitations I picked above and let the system run for a while. Every time I hit it with an impulse, record the position and velocity of the system right when I hit it with the impulse (the x component of the IRF in their paper) and the position of every vertex for a few time steps after I hit it with the impulse. I get to choose the number of time steps (the T component of the IRF in their paper).
    - Every combination of initial state \( x \), excitation \( \alpha^I \) and \( \alpha^F \), runtime \( T \), and trajectory \( x^1 \ldots x^T \) is an IRF. Here a “trajectory” is the position and velocity of every vertex in my model at every timestep after an excitation.
    - Note that it’s important not to let the system come to rest after every excitation, otherwise I would only know what the system does when I hit it with excitations when it’s not moving and is probably at its rest position.
    - Also note that this simulation process may take days. That’s the point.
  - Now I have my sampling of IRF’s. The collection of IRF’s that I sampled is called the “discrete phase portrait” \( P \).
  - Load my model into an interactive simulator, and wait for user input.
When the user hits me with some input (which must be one of the excitations I chose above, otherwise this method doesn’t work), I look up the best pre-computed trajectory that I have. So I look at the current position and velocity of my vertices, and I look at which excitation mode I’m seeing, and I find the closest match in my library of IRF’s.

Now I just play back the IRF I found in my library until I get hit with another excitation.

- Note that the current object state never exactly matches the initial state of the IRF I found in my library. So if I literally just played back the IRF, there would be a discontinuity when my object “jumped” from one IRF to the next. So I actually blend between them over some time to make the transition smoother.

Phil summarized the playback process really well:

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**Playing back the model**

At each instant, we are either playing back an IRF or stopped.

```c
while (not stopped) {
    play (x')
    if (no new impulse)
        x' = \xi(x,a^i,a^f;T) + (x' - x)e^{\lambda t}
    else if (t==T or new impulse)
        choose a new \xi by finding the IRF with the initial state closest to x'
        x' = \xi(x,aI,aF;T)
}
```

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- What did I leave out in this description?
  - This paper talks about using a very similar process for global illumination, which is also hard to compute in real-time. The concepts are the same, but I don’t understand the lighting issues well enough to describe it here.
  - When storing an IRF in your “library”, you wouldn’t have enough space on a real computer to actually store the position and velocity of every vertex at every time step. So they do all their storage in a “reduced space”. Basically you put all the positions and velocities for a given IRF into a matrix, do an SVD on that matrix, and throw away the big matrix (U). Conceptually, this is just a lossy compression algorithm that happens to be very easy to un-do in real-time. If you had a fast enough computer, you could use WinZip instead of SVD.
  - Looking up an IRF in my library is actually a bit tricky, since I never find an exact match for the current state of the system. Really I have to convert my system state into the reduced space and see how closely it matches the IRF’s in my library.
haven’t figured out (a) whether there’s a data structure that lets you do this in a non-brute-force way or (b) how much computation time this actually takes. I imagine this is a limiting factor… they do talk about caching the IRF’s that are likely to come up soon, which would definitely speed things up.

• What are the limitations of this approach?
  o You have to pick a finite set of possible excitation modes ahead of time. This means I need to know the exact direction and magnitude of force that I’m going to apply at every vertex any time I interact with my model. Clearly this is really restrictive, but is perfect for video games.
  o My real-time playback is always following one of my pre-computed trajectories exactly, even if my initial state didn’t quite match one of the IRF’s in my library. So the real-time dynamics are not that accurate.
  o I can’t take advantage of any linearity in my model to superimpose the deformations resulting from my excitations.