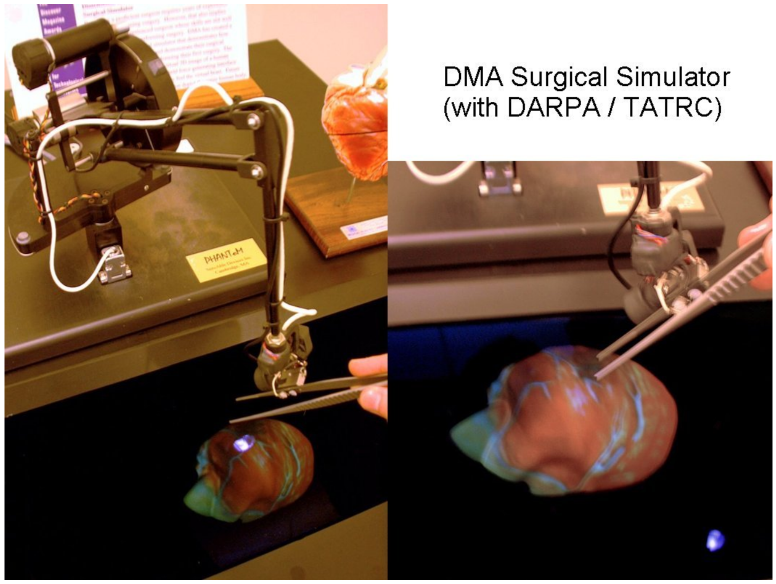
"Hi. I'm Aaron. I'm glad that I'm following Thomas' talk because they fit together very well. He mentioned a little bit about scanning living objects and how that's very challenging. I'm focusing very much on that today, and also bringing a little bit of Additive Manufacturing into it. This is very specialized. I'm going to give a little bit of background initially about how I came to where I am in terms of exploring this particular field that isn't getting a lot of attention - the overlap between additive manufacturing and 3d scanning in the context of wearable designs."

"I'm going to give an overview of wearable technologies and then give a distinction between what I'm doing and what is currently the main focus right now. I'm [going to] talk about my process, a bit of what some other people are doing, some of the challenges I've faced, and some of the solutions I've come up with as a result of that. Then, a little of speculation about the future, a little bit of suggestion about where it might go, and some things happening in other industries that connect with this, that will hopefully bear fruit in the next five to ten years."

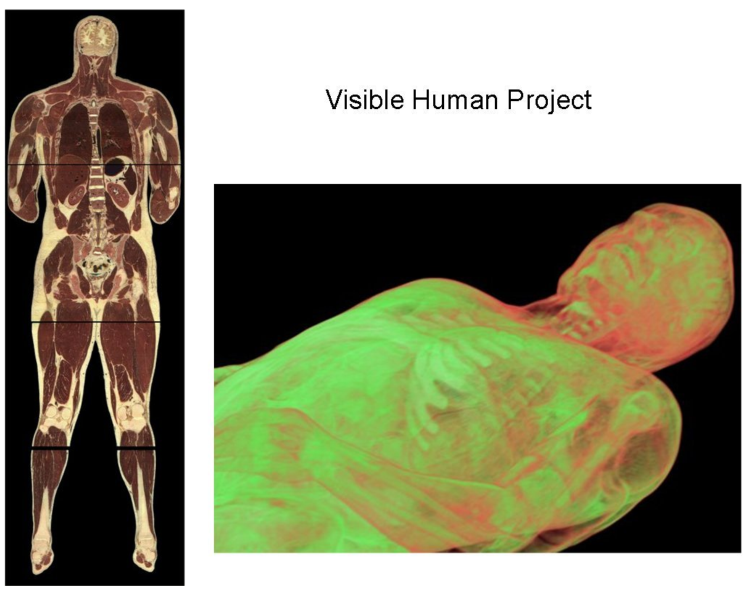
"So, to begin with, I mentioned that I worked on some 3D display technologies a few years back. Interesting stuff. I mean, You can see that's a dinosaur, a prototype. This was about 2001. These are multi-planar volumetric display technologies, not stereoscopic or anything like that, so there wasn't a lot like that. You know, this section of the conference might be becoming only 3D scanning, but maybe we should keep it 3D imaging because there is 3D imaging that isn't scanning, it's going back the other way as a display device. There just aren't that many of them right now. One reason is they cost $70,000. They were based on a DLP light engine with three chips, [so they were] very expensive."

"The work we were doing on that eventually led to a surgical simulator. This was a DARPA funded project working with TATRC, The Tele-medicine And Tele-surgery Research Center, and one of the ideas that came out of that project was the idea that you could digitize the body, store it in the computer, and use that almost as your universal medical information, the same way that right now you have very sparse medical information about your history and any medical problems you might have. The idea was you'd have a digital copy of yourself that you carry around. Unfortunately at the time, computers were not ready for that type of thing."



DMA Surgical Simulator
(with DARPA / TATRC)

“In this image, that's a very early version of the Sensible Phantom technology, and that was just a prototype, but it got the point across. Unfortunately, as I said, the computing power just wasn't there. The amount of memory required to do that kind of thing, the CPU power, was off by orders of magnitude.”



Visible Human Project

“In my experience in that, one of the things I was doing as a visualization person was coming up with ways to display the data, again, with very limited resources. So, this project exposed me to what was, at the time, really cutting edge data collection of the human body. The idea was with the Visible human project, funded by the National Institute of Health, was that you'd come up with a full digital copy of one particular person, and that would be used as sort of a template. You could practice digital surgery on that, and so on. [This is] a little bit like what we did with DNA. Sequencing the first DNA was really difficult, and now it has become almost trivial, and they expect it to become practically free in the next ten years.”

Wearable technology is:

Computing – (Integrated) Communication, information

Electronic/Optical - (Peripheral) Sensing, displays

Material - (micro) Chemical, nano-structure

Biomechanical – (macro) Hinges, Joints, Armor, Articulation, Force (actuation)

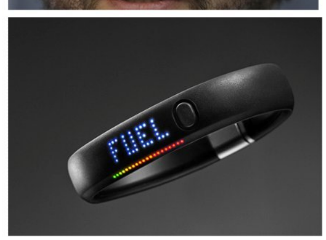
“To move forward, that is the connection between what I had done, and what I'm going to do. I'm going to come back to that whole idea of the digital copy of the self a little bit later in the talk. To give a high-level overview of wearable technology, I've got four approximate categories, and there is some overlap, but this is a good way of mentally dividing it up. You've probably mostly heard of wearable computing, a subset of wearable technology, and that's Google glass and the like. Electronic and optical, sort-of distributed technology is where I categorize things like display and sensing. They may have micro-controllers, but this is less integrated and more distributed.”

“From there, there's material-based wearable technologies. A lot of those are actually commercialized right now, more than any of the other categories. The bio-mechanical one is the focus of my talk, and it has received almost no attention except in various niche fields, not in consumer product design.”

Wearable Technology: Computing

Examples:

- Bluetooth headsets
- Nike Fuel Band,
- Jawbone Up,
- Pebble Smart Watch,
- Glass/EyeTap

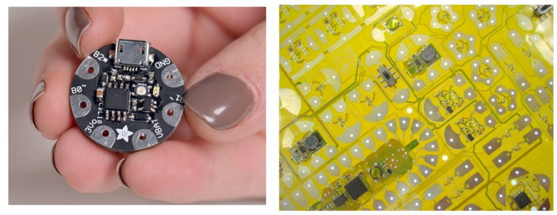


“To give a little more detail on this section (wearable computing), this is what you're going to see when you talk about wearable technology. Tiny computers that you strap to your wrist or to your head. There are several very successful products out there right now. Apple is really excited about making a smart-watch that talks to your phone, and that sort of thing. Again, not completely my focus, but it has tremendous overlap with what I'm doing, and they can easily be integrated."

Wearable Technology: Electronics

Lilypad Arduino and Flora wearable micro-controller boards

Wearable Technology: Electronics



Miniaturized/flexible micro-controller boards from Adafruit

"This is a wearable micro-controller that was designed by Leah Buchley at MIT, and then her progeny from there, founded a really successful electronics company in New York called Adafruit. They continue to develop these wearable micro-controllers. This is all hand-built stuff, so it's a very DIY type of approach. It's not for everybody because you have to know how to wire together a micro-controller. They continuously develop them and shrink them down. Now they have them on flexible Kapton stickers so they can be integrated into clothing. They're washable and durable. It's really good work, it's just very far from what you'd say is a main-stream consumer product."

Wearable Technology: Electronics

Sensor Gloves

"In more distributed, sensor technology, we're probably all familiar with the sensor gloves. There's good work there as well for tele-surgery and things like that, though not a lot of progress has been made in the last few years."

Wearable Technology: Electronics

CuteCircuit LED Clothing

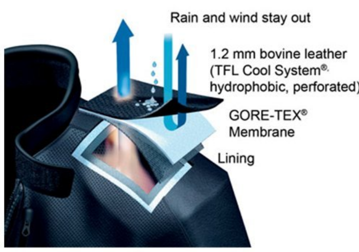
“This is also about five years old, but some more recent developments are pretty good. This is a distributed LED display. This is all very labor intensive stuff, it's not rolling off the factory lines. Usually, because of the labor involved, this is only used for rock performances. Actually, that's [for] U2 on the right, and [for] Katy Perry, a pop star, on the left.”

Wearable Technology: Textiles

Woven textiles - A 30,000 year old technology

“Moving over to the materials section of wearable technology, I consider textiles wearable technology. You wouldn't really consider it that way normally because it happens to be so pervasive, but when you think about it, it's pretty amazing that we can take natural fibers, align them so perfectly, and come up with these very complicated structures.”

Wearable Technology: Textiles



Unique properties from chemistry or
Micro/Nano structured materials

“More recently you've probably encountered materials like Gore-Tex, that have very specific engineered properties. Microscopic structures or chemicals integrated into them. On the right, that's reactive armor. It reacts to impact and turns solid.”

Wearable Technology: textiles

N12 Bikini – Continuum Fashion

“This is an additively manufactured textile material. Very recent, it's generated by breaking down a continuous surface into triangles and using a procedural algorithm to generate a spring-mesh between the pieces. It's interesting, but not very practical. The elements are about one millimeter in thickness. If you break a few of those springs, you basically destroy the fabric.”

"The section that I'm going to focus on right now is the work that I've done recently in wearables... Mostly in nylon material, but I'm going to be transitioning to thermoplastic urethane due to the flexibility, though there's still a lot of possibility left in rigid and semi-rigid materials."

"What I want to focus on is human-factor and ergonomics. I'm an Industrial Designer by trade, so sort of bridging between art and engineering. It's all about human-factors. Human-factors includes psychology and marketing and things like that, but here I'm really focusing on bio-mechanics."

"The point I want to make is that by continuous capturing of [data]- we have the data anyway - by re-purposing that [data] we can come up with a personalized anthropometric record of each person that can then open up a very wide number of other applications. I've got a few of those here. Veterans of this show will remember Scott Summit at Bespoke innovations in San Francisco doing some really nicely styled prosthetics, additively manufactured."

"Body Armor. It hasn't really been done that much yet due to the fact that most of those fibers are much longer than the layer thickness that you're going to find in additive manufacturing systems, but of course [in] some of the initial fragmentation layers they [use], where it's a combination of ceramic and metal composite, it could be very effective, though it hasn't been commercialized, it's being researched.”

“Sports. Again, a lot of money goes into this. A lot of sensors can analyze the performance of the athlete and then use that to provide them with the right products, or therapies, or nutrition, or whatever it happens to be, to improve their performance.”

“Extreme environments. Antarctic expedition, mining, whatever it might happen to be. That's where I see this type of thing being adopted first. I'm the first to admit you're not going to be wearing this to the grocery store, or whatever, for a very long time. My market is really for performers and artistic purposes at the moment, and I'll go a little more into why, my reasoning for that.”

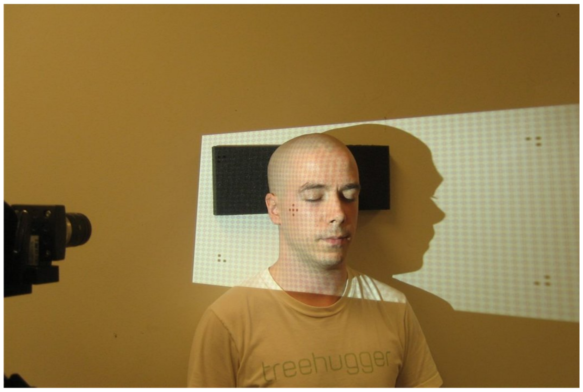
“Integrated functions. It's a little difficult to predict what the results will be. It's a little bit like with smart phones for example. One app can come out and it really changes the lifestyle. Those are cultural effects. They're very difficult to predict.”

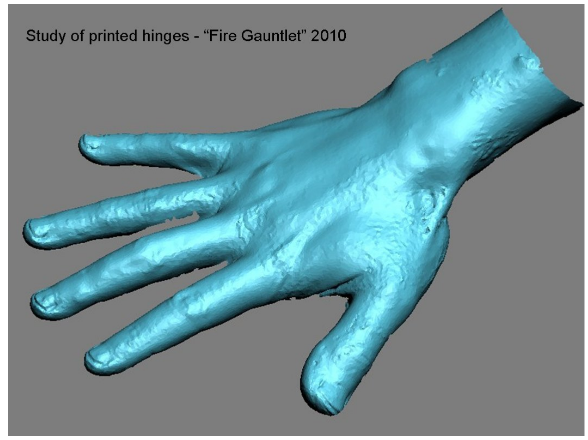
Additive Manufacturing market in 2011:
$1,700,000,000
(Wohler's Report)

Apparel and accessories market in 2011:
$1,778,500,000,000
(MarketLine Research)

“I know as soon as I say "fashion" I'm losing half the audience at this conference. I get a lot of eyes kind of drifting around. Well this one [slide] - people like numbers so I'll bring it back down to earth a little bit. According to Wohlers we had 1.7 billion for the entire additive manufacturing market in 2011, and for apparel and accessories, you might notice that that number is more than a thousand times larger. So that include farming fiber crops, weaving of textiles, cutting and assembly of garments, shipping them to retailers and retailing them. That does not include cosmetics. It does not include fashion marketing and magazines and everything else related to that industry. If I were to put that in there we'd be looking at close to three trillion. It sounds amazing, but I looked up the numbers and it's actually true. The only larger industry on the planet is food, for obvious reasons.”

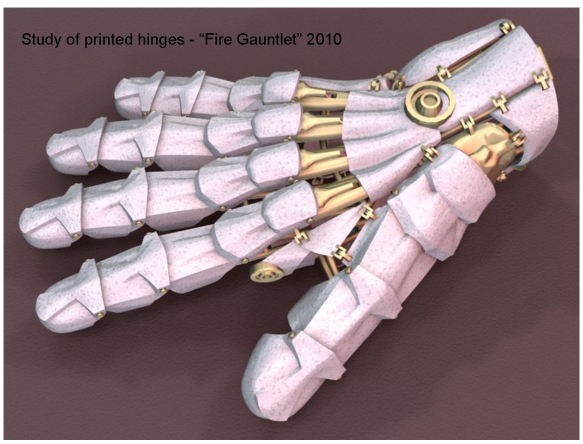
3D Scanning for wearable designs - 2010



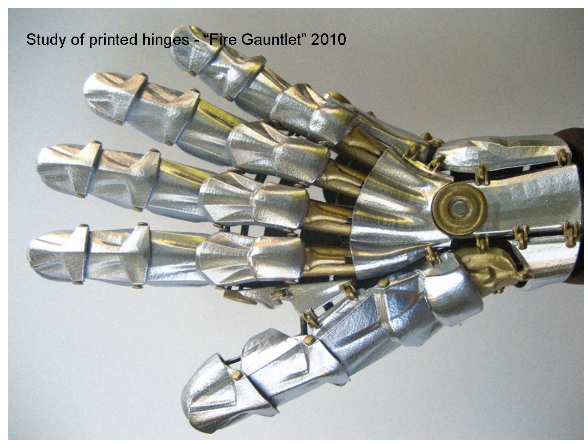


Study of printed hinges - “Fire Gauntlet” 2010

“In more recent years, long after the 3D display company and surgical simulation stuff. I began getting into 3D scanning the body. I was doing some reverse engineering of [industrial] parts, and this was an interest of mine. I had some designs I had been sketching for several years. Working with an associate who was building scanners, I felt enthusiastic enough about it to shave my head and get fully scanned. I made some interesting hats and things like that.”

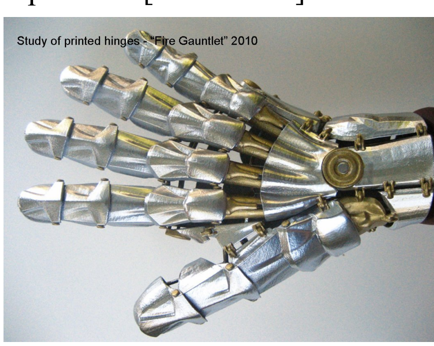


Study of printed hinges - “Fire Gauntlet” 2010

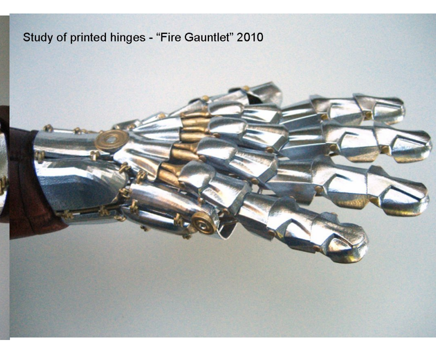


Study of printed hinges - “Fire Gauntlet” 2010

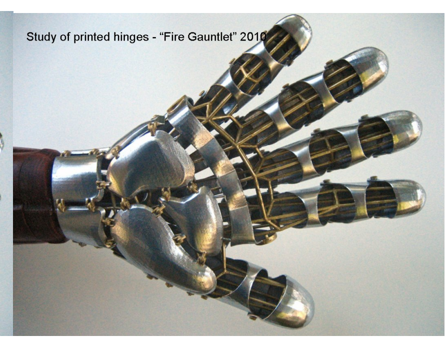
“I went ahead and some old sketches I'd been working on into sort of "fantastic" designs to analyze the results of working with the joint locations and things like that. This is an additively manufactured glove project. It is laser-sintered nylon, I just finished it with a metallic finish to make it look better, but all those hinges are printed with the proper clearances, there's some faux actuators, just to give an impression [of function].”



Study of printed hinges - “Fire Gauntlet” 2010



Study of printed hinges - “Fire Gauntlet” 2010



Study of printed hinges - “Fire Gauntlet” 2010

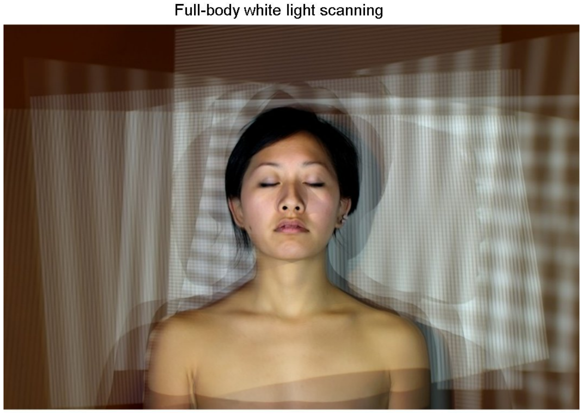
“This was actually done for Siggraph 2010. It speaks to the potential of what can be done with 3d modeling, 3d scanning, and additive manufacturing, when we put all those things together in the mature state that they're reaching right now. It was a popular project.”

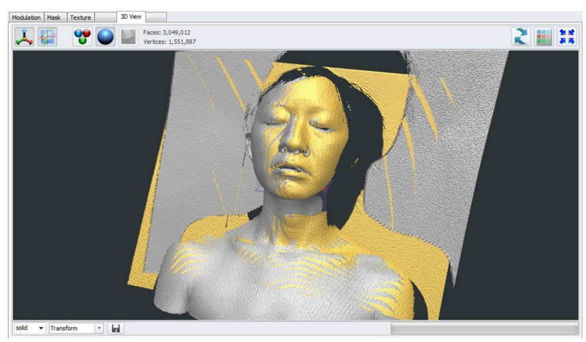
Fitted wearable tech from 3D scan data, produced with additive manufacturing

- -Designed from surface information and body mechanics
- -Very little movement relative to skin
- -Ideal fit and comfort, even with semi-rigid material
- -Clothing as a platform for sensors, computing
- -Opens up many possibilities for design/aesthetics

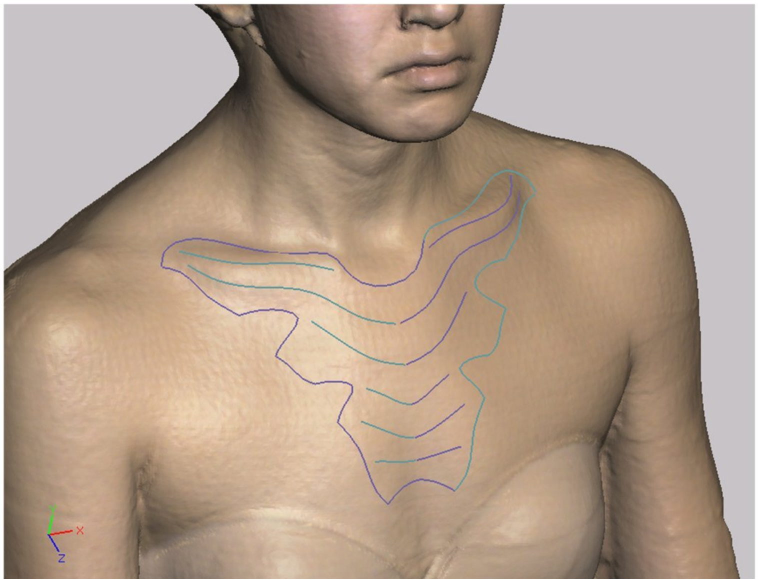
“I continued to consider the issues that I had encountered when I was working on those projects. There's quite a few of them, but at the same time I can see some benefits to it as well. When you're talking about materials that are semi-rigid and very closely fit to the body, there's not going to be a lot of movement relative to the body. So, when we're talking about sensors... that can detect muscle motion for athletes or for therapy... it provides a number of advantages, if we can address the issues with proper fit, since we're trying to scan an object that is changing shape constantly. Also, obviously, aesthetics. You have great control over aesthetics when you can digitally analyze and quantify the shape.”

Full-body white light scanning

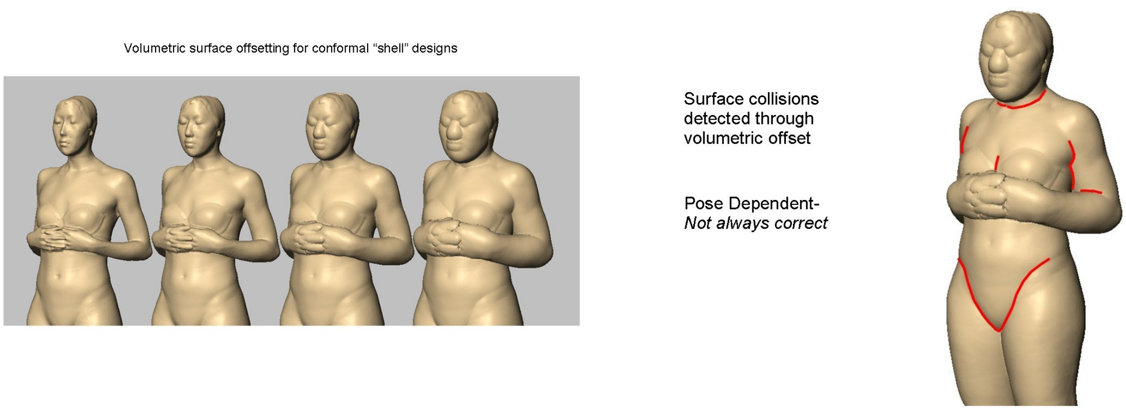




“This is an earlier implementation of the project using structured light, which has positives and negatives, but is probably not the ideal process. Right now, some high resolution photogrammetry might do a better job because the technology has become so mature, but structured light is very flexible. I can change the field of view, scale, and given that the subject is leaning against a wall, holding her breath, the results aren't too bad. You can see that the scans interpenetrate fine, so you can see there is halfway decent alignment.”



“When it comes to the design, that's where the challenge is, because you're dealing with soft tissue that changes shape, as a person changes [position]. really the places to put [printed designs] are areas that don't change shape, at least not very dramatically. When it comes to the interconnecting pieces, you then have a more complicated problem to solve. Fortunately, with additive manufacturing, a complicated mechanism is not hard to produce. Once you produce one of them, and you come up with a procedure for building, it actually is very straightforward.”



“I was working on that issue, mostly using surface offsetting to generate sort of shells, and I could have those shells move through each other. It works up to an certain extent. You can go up to a certain thickness, and then you see that the surfaces collide with each other. This is using volumetric offsetting, not polygons or anything like that. I'm using the the SensAble system, which is voxel-based. You can see it eventually creates some seams when you offset, and those seams mark the areas that are the ideal points for the separation between solid panels, and then the space between the panels is relative to the amount of flexibility you need.”

Direct Design for Customized Digital Apparel

A boundary sketch drawn on the skin

Design is always registered to actual anatomy

Accurate registration preserved with color scan

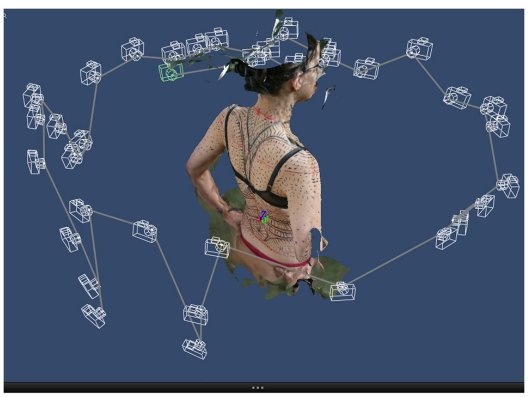
Reconstruction is assisted by the sketch

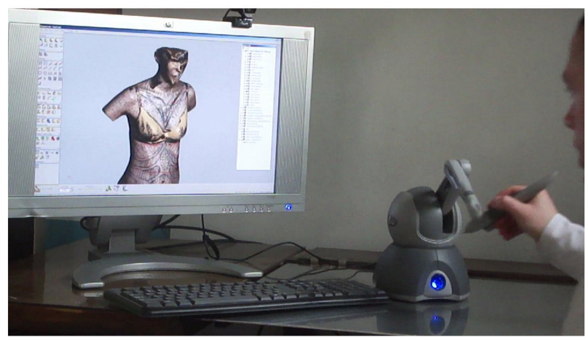
Fitted designs produced by AM

Intuitive enough for clients to contribute

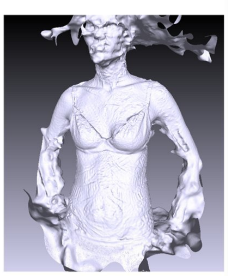
“I was realizing that it takes a lot of analysis in post, with digital data, to figure this out, but when I'm standing there with the person, it's not that hard at all. I combined that with the fact that if I wanted to work with other people - and I almost always do have the person I'm working with contribute to the design - I don't just want me making the thing around someone, you know, it's an interaction, so I came up with the idea of drawing it directly on the skin, and then using full-color 3d scanning to capture it. That's especially appropriate because, yes I have the structured-light scanner with me, but if I want to collaborate with someone om the other end of the country, for them to go get scanned, their full body, that's several hundreds dollars at least. It depends on the quality. A Kinect, by the way, is not good enough quality. You'll need at least 1% accuracy over the entire scale of the object. Maybe subsequent generations of that technology might work , but for now structured-light has been the best example. Within the last two years we've seen a big jump in photogrammetry accuracy. Just to be clear for people who were here for the earlier presentation, this is distinct from the type of photogrammetry that is used for alignment in scans, with the Creaform scanner and the like. There are no tracking dots. Instead of identifying the location of a dot, modern photo-based photogrammetry just finds any features, corners or blobs, in all of the pictures, and it's an unstructured algorithm, it figures out where the camera is taking the image from and comes up with it that way. The idea is, since I'm drawing the pattern on the skin anyway, I'm creating the design not just without 3D modeling, but without any technology at all, just makeup. The added benefit of drawing it on the skin is that I'm now creating features that can be tracked by photogrammetry software. When I take that a little further and just fill in around it, I've then created a whole bunch of features so that the results of the photogrammetry are far better than they would have otherwise been.”

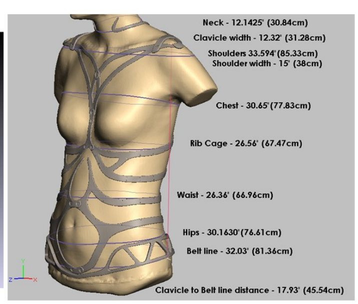
“So the process is: I draw it on the skin, that ensures accurate registration, and it's easy. Anyone can do it.”

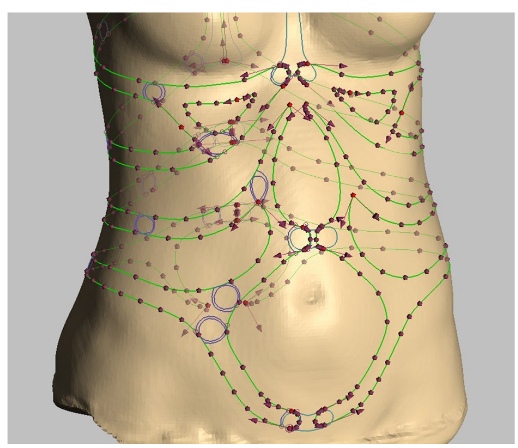




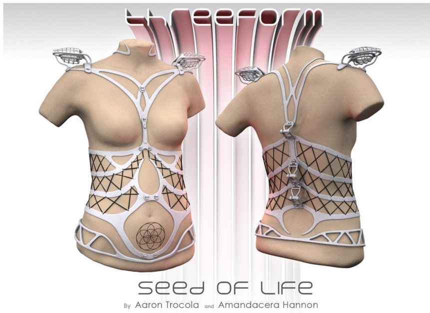
“This illustrates a little of the process. Drawing it on the skin. This is the photogrammetry reconstruction, showing about 30 different images taken from various directions. To clean up the data, to build the extruded surfaces, we're using the Phantom Omni haptic interface to clean up the data and build the surfaces.”

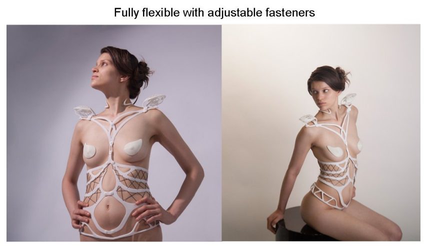




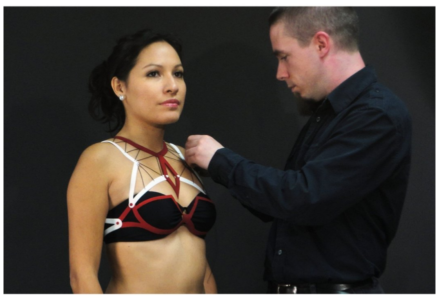


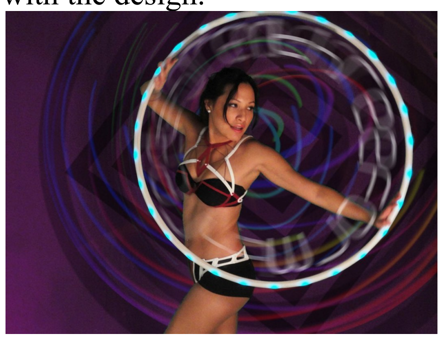
"You can see the original data on the left there - a real mess. Then on the right after being cleaned up and separated into sections. A lot of control points. So, it's difficult to transfer an existing design from one body to another, but the results are pretty good."





"This is showing a bit of the results. This is all flexible material. It's only two millimeters thick. It's got hinges and fasteners printed along with the design."





"Here's another one. You can on the shoulder there, a ninety degree angle change on the...structure. You can't do that with fabric. This all snaps together. Those circular fasteners act as hinges, so there's complete freedom of movement."

Challenges:

Scanning one pose does not capture enough data

Difficulty adapting existing designs to another body

Difficulty generating usable models from customer designs

Process is currently very manual, labor intensive

AM production cost is still high

AM materials and processes not yet ideal

No system available to integrate functional components

"The issue is if I make one design, transferring that design to another person is virtually impossible. They're different shapes. Even if they're similar in size, just projecting based on surface normals doesn't work. What I'm identifying as one of the many challenges is that. The labor-intensive process of moving things around, and some other issues there as well."

Solutions:

Build hybrid parametric and statistical models of
The body, personalized based on available scans (surface/vol)

3D line-finding algorithm that captures intent and
discards errors

Automated generation of segmentation, seams, hinges, fasteners

Soft material, multiple material printing

Develop miniaturized wireless computing modules to add function

“The solution that I've found is that there's an existing body of work in the 3D animation world where you can change the proportions of one performance and make it fit with another. There are some other issues that could be addressed farther down the road, five or ten years away, but in the short term we can make a general model using this 3D animation [system].”

The Integration Problem:

-Data is only useful with context

-Individual variation makes classification difficult

-Biological subjects vary over time and position

-Different technologies produce very different output

Analogy with Mapping

Geographic Information Systems can accurately classify data

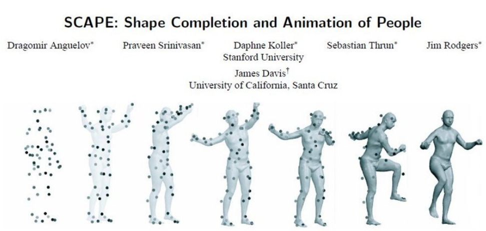
Data becomes much more meaningful with spatial location.

Wearable data capture (bio-informatics) is like a
meteorology station for the body

“One thing is want to say, is that this [analogous with] mapping of the Earth. At one point mapping...was very difficult, but once we had a solid model to represent it, it became very easy, and all the information is suddenly much more useful. The analogy I make is that it a little bit like having a meteorology station. If you didn't know where that station was, it would be almost completely useless. You wouldn't get anything from it.”

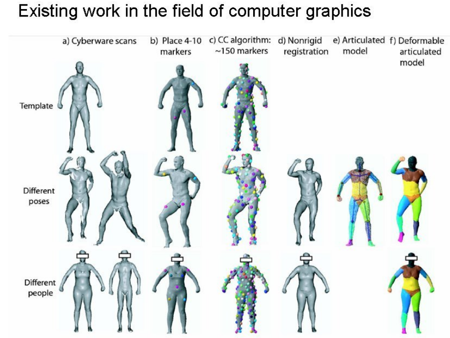
Transforming and Aligning data

Existing work in the field of computer graphics

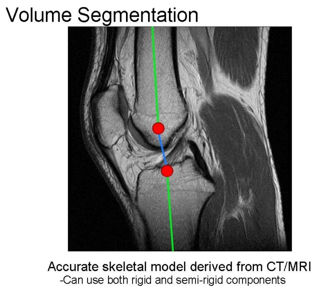


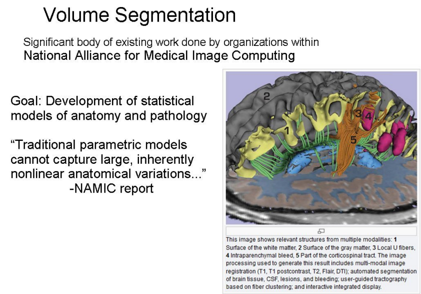
Transforming and Aligning data

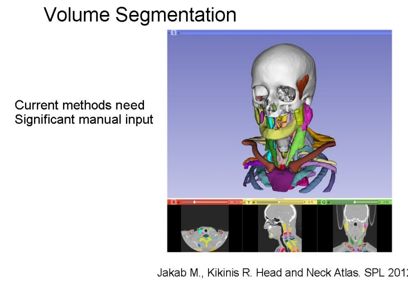
Existing work in the field of computer graphics



“I'm referencing a paper here from Siggraph. Most of this work was done from 2007 to 2010, and it basically uses tracking points0 to come up with a statistical model of the human body, and what's interesting [is that], because it's not parametric, it's statistical, it simulates muscle bulges and things like that without having to simulate whats beneath the skin, bone and muscle. It's just simulating the surface, and statistically reproducing the bulges.”







“To extend that into the volumetric domain, you could use that model and apply that to all the data that's collected of a person during their lifetime. By analyzing the skeleton, we come up with a rigid frame that guides the surface, and that guides the deformation, then we can come up with a transformation where we can distort CT and MRI data into a universal coordinate set, and project our design over to that. Then you'll be able to make an animation of the person as they grow, distorting all that volumetric data in to one [space]. Some of this has been done, in terms of the segmentation, but not the distortion, only separating the tissues out. Right now that is still very tedious and manual. They have body atlases, but they are not universal, they are of a particular person. What we really need to do is come up with a standard way of transforming that. That way you can make one design, and the software will convert that design so it will fit to any person, no matter what there size or shape or age.”

Privacy concerns

Companies must have access to the data to use it.

Risk of discrimination based on potential health issues

Extracted surface model is personal as medical data,
but with far more commercial applications

Cloud-based systems can be compromised

Solution: User owns their mapping transformation

“I have to mention privacy because that information, that's your medical data. I think there's an advantage to having each person own that because you'll be able to transform that product, it may be through a third party, encrypted system, but that way it ensures there won't be intellectual property issues and privacy issues. For example, if I have a design adapted to me, I can't then sell it to someone else just because I have the STL file. I's only adapted to me, so that problem does not exist in that way of thinking of things.”

Additive manufacturing and 3D imaging
Future developments

Fully tracked 3D shape input/output with prediction
-Dynamically aligned 3D video capture
-Dynamic alignment of digital pen input
-Projection of design data onto a moving body

Integrated, conformal circuitry

Ambient power systems reduce need for wiring

Node-based wireless micro-computing architectures placed in-situ during AM build process

“In the future, as I mentioned, we want to have things very much aligned with a universal model. Once we accomplish that, where we can track from sparse 3D scans to fit body data to that [universal 3D] image, we can then do dynamic 3d scanning at high frame-rates so the painting thing won't be necessary. We'll use an interface pen similar to the haptic pen in terms of tracking but without the force-feedback.”

“With additive manufacturing advances we can look forward to conformal circuitry. Node-based architectures placed in-situ within AM builds- what I mean by that is that chip you saw before could become about the size of a grain of rice and have a little coil on it that receive ambient electromagnetic field pulses, wake up for a fraction of a second, do its job, re-emit a pulse with its data, and that way we don't have to worry about any kind of wiring or power [source]. It a little like the Near Field Communication (NFC) devices used in cell phones right now.”

“So that's it. That's my idea and some of the work being done in wearable technology, specifically in the bio-mechanical segment. I look forward to seeing a lot of interesting advances as scanning and additive manufacturing technologies progress. Thank you.”