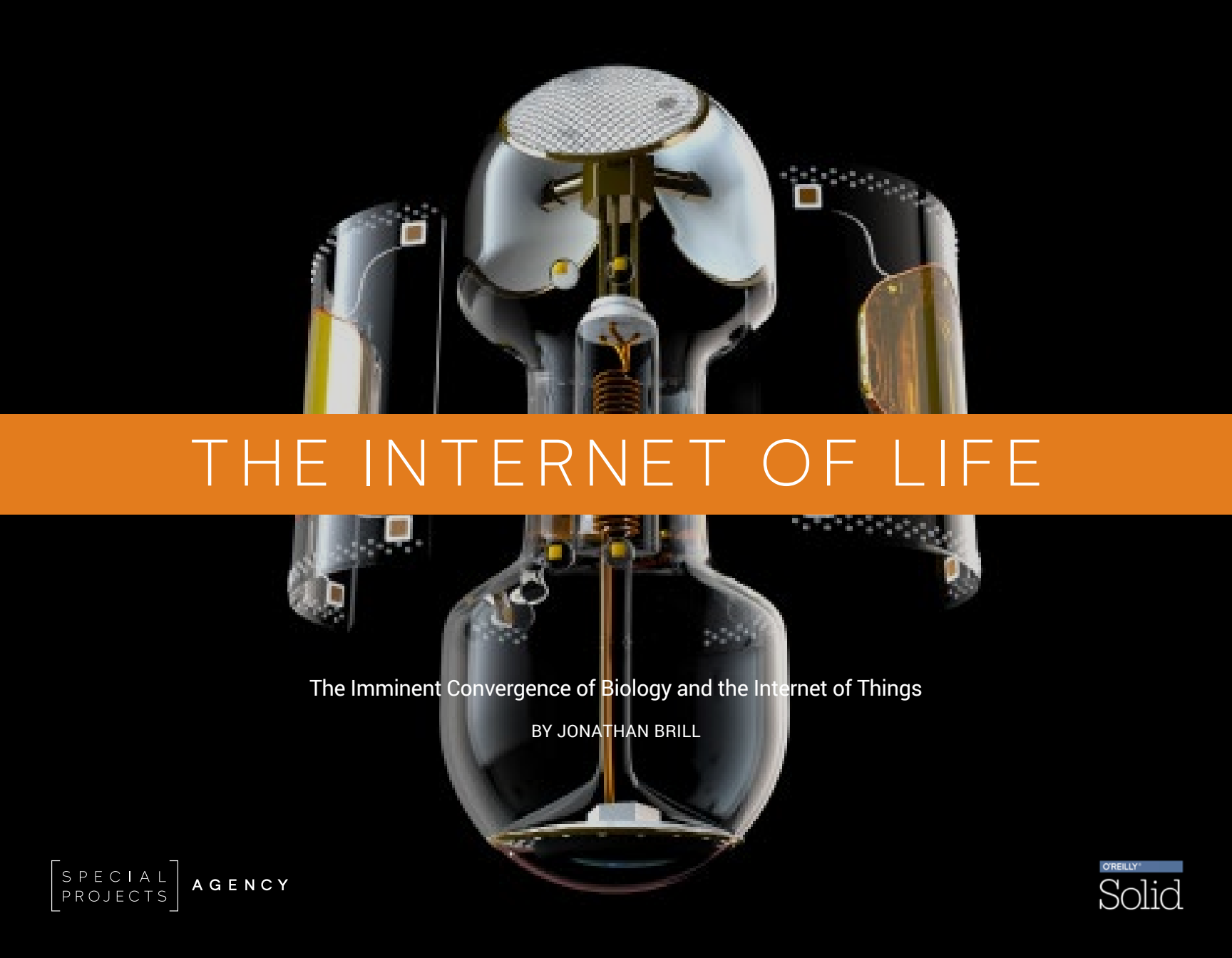

THE INTERNET OF LIFE

The Imminent Convergence of Biology and the Internet of Things

BY JONATHAN BRILL

SPECIAL PROJECTS AGENCY

O'REILLY Solid

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"What happens when biology starts to jack into the internet?

Future Lab 2030

Over the course of Solid 2015, we held a 2-day Future Lab: a structured brainstorming session where we worked with thought leaders in a range of industries to look at the future computing from three perspectives:

Global Meets Local | **Synthetic Biology At Home** | **The Internet of Life**

Image Courtesy: Special Projects Agency

Welcome to the BIoT

Some of the ideas that emerged during Solid 2015 will certainly drive global economic growth, but not in the ways we're currently imagining. The direction we know we're going looks something like this:

Everything is becoming data
Tagging, tracking and pervasive sensing is moving from the palette level to the part and material level.

Emergent systems are managed in realtime
Modeling is becoming dynamic and highly granular.

Separation of information from objects
Objects will increasingly co-mingle with code that is used to design them and will increasingly morph and evolve, either as 4D materials or biological materials.

The line between goods and services becomes increasingly blurred
As product development and manufacturing continue to cycle faster, customer perception will not distinguish between the two.

Form follows materials
As information becomes a material, modularity will become increasingly important.

Things are starting to think
Increased agency within systems is becoming possible as a result of result of better data, access, and analysis on each layer.

> "How will technology shape human experience in the next 15 years?

We see the IoT as a paradigm shifting technological advancement.
In truth, we're looking at the foothills and believe we're looking at the mountain tops. We are on the cusp of changes that will not only shape the way we live, but shape our very being.

Since the beginning of civilization there have been technological breakthroughs that have transformed collective human experience. 10 million years ago people made tools from what they could find, wood, stone, bones. 8 million years later they discovered fire. A million years after that and we're wearing clothes. The cycles got shorter between these watershed moments. We made boats, began to farm, invented the wheel then the alphabet. And so it goes.

During the 20th century the pace of technological development accelerated and spread throughout the world faster than ever before, setting the stage for where we are today. Radio waves, airplanes, cars, plastics, television, refrigeration, vaccines, DNA, nuclear power, space travel, computers, the Internet, mobile communications. The world our grandparents were born into is fundamentally different from the one in which we now find ourselves.

The computation platforms that have driven global prosperity for the past 40 years are about to hit their physical limits. As we begin to look at atomic-scale manufacturing, it will, in fact, be impossible to get any more precise using current tools.

Systems are increasingly able to anticipate user need and maintain themselves. These are the promises of the IoT. But we haven't even begun to perceive the role this next generation of products will play in our lives.

What's the big consumer story here? The game changer that came out of Solid is that consumer bioelectronics, a new class of devices that draws from the fields of artificial intelligence, biology, and electronics will soon layer into the IoT technology stream.

In the next few years, consumers will be able to design DNA, grow life, and produce customized molecules at home. What happens when billions of people start to create synthetic life? Up until now, these have been the powers of gods and Craig Venter. If the Internet was a change on the scale of the printing press, this has the potential to be a change on the scale of agriculture.

What happens as chemical sensors, bioelectronics, new life forms, and the molecules that they produce start to jack into the IoT and leverage analytics?

Welcome to the BIoT. The Biological Internet of Things. The BIoT is about much more than the control of information. It is about man's harnessing of life on a global scale. This new data-driven ecology is fertile country. We are just learning the pathways within cells and have not modeled an entire one — much less an organ or a city — but the path is clearly set.

Global Meets Local

The Uber-ization of everything is globalizing. As it does, it will reshape production pipelines, causing new combinations of product bundling to meet the demand for instant access to physical goods at commodity prices. Food is one of the first low-cost, mass produced materials to be tracked from engineering all the way into consumer recycling.

As we move from the IoT to BIoT, we will increasingly be able to address core issues throughout the food chain:

Management of food waste
Parting and bundling will become increasingly dynamic, enabling more value added through the chain while decreasing the risk of spoilage.

Customized production
New service networks will respond to emergent market opportunities, rebundling materials and components up until the point of delivery. This trend is likely to appear in a range of highly customized end product applications.

Dynamism down the food chain
A continued push toward product customization will keep materials in raw or partially finished form further and further down the supply chain.

Automated & competitive delivery
Increasing labor rates in cities will drive repetitive tasks like chopping vegetables to mechanized solutions or back to the source of component production, where labor rates are lower.

Because of its global, perishable nature, and susceptibility to environmental change, food will be one of the product categories to watch. Over the past 10 years, increasing standardization of shipping, modified atmosphere packaging, and quality assurance from seed to fork have significantly improved the cold food chain in the U.S. and are set to do so globally. Multi-source product bundling will become more commonplace outside of cities like New York.

For example, a food delivery service might bid on other tasks, such as picking up beer and cigarettes. As this trend continues to grow, it's clear there won't be enough Uber drivers to support this new economy.

Online ordering combined with autonomous delivery vehicles will continue to decrease the need for retail storefronts; many last minute production services will consolidate to provide a more integrated, more efficient offering. Dynamism further down the supply chain allows value creation from former waste materials. Scrap from one dish can become a key component for another. Cabbage from an Irish boiled dinner can be used for kimchi in a Korean meal. Other food services will compete by finding new ways to put their product closer and closer to the consumer in a bid to provide the fastest service.

> "There are huge logistics and marketing advantages in holding stock closer to the consumer... It's what you do with bulk materials after that point that adds all the value.
>
> – Danielle Applestone, Other Machine Co.

People will have more **on demand, customized options than ever before**, while at the same time, producers will have more control and efficiency through the end of the supply chain. At the global level, with production delivering to a global footprint, **there will be more redundancy and less risk** throughout the food supply chain.

Image Courtesy: Special Projects Agency

Case Study: Chef's Garden

In the US, high end farmers, like the Chef's Garden in Ohio, are tracking the moisture, nutrition, and temperature of vegetables from the seed room to the plate. As the cost of tagging drops below $.02 , the demand for this technology will grow exponentially.

Chef's Garden can select a product, such as fava beans, take them immediately into a cold environment, pick them out of their pods, and have them shipped within 3 hours to anywhere in the world for next morning delivery.

Because of the high level of temperature control throughout the process, even the most delicate leaves and flowers will last a month in a restaurant cooler.

Image Courtesy: Chef's Garden

Image Courtsey: Special Projects Agency

Danielle Applestone

Co-Founder, Other Machine Company

OMC is a San Francisco-based company bringing manufacturing tools to everyone. Following her PhD at the University of Texas, Danielle worked on a DARPA-funded project to develop digital design and CNC manufacturing tools for the classroom.

Jon It feels to me like Other Machine Company is at the avant garde of a real change in the way we produce, and the way we think about manufacturing...

Danielle We can do a redesign of a product frame today with some features, for example, to make assembly easier. We can just roll that change in, and the very next batch of frames that comes off the line will have that new feature in it. There is complete flexibility in what we do.

Jon Why is that flexibility important?

Danielle We innovate continuously, kind of like you do in software. This allows us to adjust as we go. We have discovered that the pace of hardware development is so quick that you have to put a product in the wild to test it as soon as possible and you need to maintain flexibility in your process. The only way that you do that in a scalable way, is to know the entire story of every part of your product: Where it came from, who the manufacturer was, what was the lead time, how much did it cost, who did the quality control, who is the one who assembled it, and how much time did that take. As soon as a problem happens, you have to laser into it, find all the patterns, then proactively solve that problem for any other machines that are out in the world.

It is really important to know the entire story of a product and correct as you go, because you never have time to do enough product testing. As we set up our business, this approach as at the core.

Image Courtsey: Rob Hanson

Jon It seems like you're keeping material in its commodity state as late as possible in both your own organization and for your customer, how does that role out at scale? What's your vision for the maker movement in 2025?

Danielle For small manufacturers, there are huge logistics and marketing advantages in holding stock closer to the consumer...particularly for large items. Places like Ace Hardware will provide bulk materials that things are made out of: aluminum and wood, Delrin and fabric. It's what you do with it after that point that adds all the value. The raw materials playing field will be increasingly level and we need to add value and character in our own way after that.

> "We innovate hardware continuously, like you do in software. This allows us to adjust as we go.
>
> – Danielle Applestone, Other Machine Co.

Jon As China starts to robotize, it seems like there's a strategic advantage in their lower cost of energy for producing, particularly plastics and aluminum. How does that impact the value add that you need to provide at the end of the supply chain? Where's that balance and how does that start to work out?

Danielle Robots and energy are two elements of being competitive from a cost perspective, but in the future, continuous innovation through craft and design will allow companies to be competitive in areas that have nothing to do with price.

I just read this article in the Japan Times recently about how some of the robots in Toyota's factories being replaced by people who were building things by hand and actually hammering out crank shafts by hand. The reason was, they're amazing at automation – they literally automated and data tracked everything and optimized it to the point where they hit a limit and forgot that it was important for people to build materials intuition, for people to be able to learn with their hands.

You want your craftsmen and engineers to not only be able to program a machine and build a system that can automatically design an arm or whatever it is. You also need them to be continuously refining their craft, building things by hand, because a robot's only going to be so good at building things for you. You have to program it, let it do its thing and then go back to learning things that maybe you can't even put into words.

PREDICTION

Biotech, enhanced cool chains, and gas monitoring will make it possible to tag, track and optimize the quality of organic material through longer and longer supply chains—at an individual item level.

CONCEPT

Micro Reefer

The microreefer is a modular food transportation system that takes product from the farm through transport, including marine transport, to the commercial kitchen, managing/tracking ripeness and freshness throughout the process using:

- ***chemical/environmental sensors***
- ***hormones***
- ***precision temperature/humidity management***
- ***inert gasses***
- ***smart packaging that visually confirms the quality of the product***
- ***can be pinged about the quality of the product***

Units will share a common footprint and pack efficiently into reefers with an eye toward robot-driven pick and pull throughout the supply chain. Reefer trucks, cargo ships and warehouses can directly, dynamically and precisely manage product inventory.

The smaller package size will allow more fabrication to happen on farms and in low labor cost regions.

Image Courtesy: Special Projects Agency

PREDICTION

Robotics will enable new models for parting and bundling across the supply chain.

INNOVATOR INTERVIEW

Renee DiResta

VP Business Development, Haven

Haven is a private marketplace for booking ocean freight shipments. Prior to Haven, Renee was a principal at seed-stage VC fund O'Reilly AlphaTech Ventures (OATV).

Jon What technologies are reinventing freight logistics?

Renee Some of it is just software mediation of low-hanging fruit: for example, track and trace. How do we make a more efficient track and trace system? Startups are looking at doing things like maintaining what's known as cold chain in agriculture for perishable products. Shippers want those goods to move at a certain temperature. If they go above or below that temperature they rot or are not considered safe for human consumption any more. This requires looking at inexpensive sensors, and the instrumentation of the containers themselves.

Jon As the materials and components stay in their commodity state later and later in the supply chain, how does this impact shipping?

Renee It's interesting seeing how innovation in manufacturing and logistics go hand in hand. A company's logistical operations are driven by where it purchases goods and locates its factories, and by where it delivers products to end customers. Supply chain managers are looking at innovative ways of shipping materials rather than finished products. Here at Solid, Mickey McManus of Autodesk mentioned you could move 19,000 Barbie dolls or enough polymer powder for 250,000 Barbie dolls in one 40-ft container...As manufacturing changes, particularly within the U.S., as lights out factories emerge, as robotics transform the cost of getting a product made, what are our customers going to be importing? What are they going to be moving? Will they import the finished goods or will they import the powder at that point? I can't predict the future, but we're starting to see a major shift take place.

Image Courtsey: Rob Hanson

> If you are flying over plastic powder from China, depending on the finished weight of the product, you can cut lead time and finish the manufacturing in the U.S. for similar prices.
>
> – Renee DiResta, Haven

Image Courtsey: Special Projects Agency

Jon What are the interesting opportunities in this space?

Renee Many people in logistics are concerned with the day-to-day challenges of managing demand, because carriers are dealing with very large, physical assets (container ships) and don't want them to sail with empty slots. In the next few years, the decreasing cost of data analysis, sensors and satellite imaging are going to make the logistics industry much more dynamic by providing granular, realtime insight into the supply chain. With that type of insight, costs will start to more closely align with true supply and demand.

Image Courtsey: Ingrid Taylar

PREDICTION

Dynamic bidding and autonomous delivery vehicles make it possible to add value through the last mile.

CONCEPT

Butler Bot

Networks of autonomous vehicles will enable a new class of inexpensive ($5K) ultralight, self-driven tricycles that move at 5-15 mph.

These trikes would be customizable and assembled in the city where they are used, leveraging 3D printing of metals and composite materials.

The trikes might transfer and bundle orders on the street, much like UPS and FedEx do today.

In the case of a home delivered meal, this would move competition from the app down into the delivery pipeline. For instance, a store owned roving 'Sommelier-bot' and a 'Chinese Food-bot' could be trolling the streets, extending the geographic reach of the stores and drop components for the final delivery to a consumer-owned/subscribed 'Butler-bot' assembles the order.

Image Courtesy: Special Projects Agency

Andrew Hessel

Distinguished Researcher, Autodesk

Andrew is working with Autodesk Inc.'s Bio/Nano Programmable Matter group, developing tools for designing living and nanoscale systems. He is the co-founder of the Pink Army Cooperative, which is aiming to make open source viral therapies for cancer.

Jon What is exciting you most about the Syn Bio Space?

Andrew Synthetic biology is growing at an incredible pace. Just this past year, we increased the size of the DNA alphabet by 50%. It's really quite astounding how this whole technology space is accelerating...and how much room there is left to run. Despite all of the massive scale computing in the world, we don't have a computational model of a single living cell.

The most advanced supercomputers are, by many orders of magnitude, simpler than the simplest bacteria on earth. Importantly, and perhaps thankfully, none of our technologies have developed self-replicating systems.

The cell as a "tractable machine" that can be turned on and off, and can be programmed. In many ways, cells are the original 3D printer, and a self-replicating one at that. Do you dream of a world where you can print a flashed circuit board? You have already done it, billions of times. Today. The beauty in the process is that it works so well, it is invisible to us.

This operating system is in its trillionth iteration, and is being beta tested by an immeasurably large user group.

Image Courtsey: Andrew Hessel

We're starting to hack life on a grand scale.

Jon What interesting products do you see coming down the pike?

Andrew My wife and I recently had our first child. It got me thinking about the energy required to build a human. We are, when you think about it, a self assembling mesh network, made of milk, with 40 trillion cells...

Image Courtsey: Rob Hanson

> "We are, when you think about it, a self assembling mesh network, made of milk, with 40 trillion cells.
>
> – Andrew Hessel, Autodesk

Image Courtesy: Muufri

Andrew Muufri is engineering yeasts that produce the protein compounds in milk, then adding them to water. In the process, they are removing the dairy cow (and a large carbon footprint) from the equation. People think of milk as coming from cows, yeast-milk is freaky, right...but how different is this, really, than culturing yogurt or beer? What's really interesting about the growth of this technology over the past couple of years is that it is relatively simple to do yeast engineering. Yeast can be "trained" to produce any biological compound that has ever been identified, from insulin, to milk, to cannabinoids. What could you build?

PREDICTION

A combination of soft robotic manufacturing and molecules produced to order will enable mass customization at a molecular level. Humans will likely continue to work in these systems to provide systems engineering insight.

CONCEPT

Domino's For Health

A food delivery service that provides different styles of food. Soft robotics manage repetitive tasks, such as prepping ingredients and plating the finished product. A human likely stays in the loop to deal with certain aspects of finishing.

Pre-prepped ingredients are infused through vacuum marination with flavoring after initial cooking using techniques and then finished and sauced.

Flavors are optimized on a per item basis to the user's personal taste and nutritional needs based on realtime feedback from wearable and ingestible devices (see more below). Sauces are created by the mixing of flavor additives, similar to those used in industrial food production. Finished food is delivered to Butler Bots (See case on p. 25).

Image Courtesy: Soft Robotics

SCENARIO 2

Sythetic Biology at Home

Chemistry is the base business that moves the world economy. It is at the root of every major industry. Right now, it is happening in factories around the world. What gets shaken up when molecule production moves into your home?

For example, what if the next generation of food innovation coupled convenience and taste with personalized nutrition and home brew pharmaceuticals? Synthetic biology and DNA manipulation would rapidly allow consumers to develop new strains of bacteria, that can produce customized molecules in living organisms.

Food technology over the past century has focused on separating the nutrition, flavor and texture aspects of food so that storage, shipping, processing, and finishing can be managed more effectively. Over the past 20 years, we have seen a diffusion of these industrial food technologies into institutions, then restaurants and now, increasingly, the home.

While millennials are our first generation of digital natives, have we already raised several generations of chemical natives? Today, much of what we eat, even from high end "natural" CPG producers, is enhanced with extra flavor molecules and micronutrients that are lost between farm and delivery.

Flavor, texture, and nutrition modification technologies have been seeing an uptake in home use for more than 50 years. For example, early on, vitamin pills and artificial sweeteners entered the home for nutrition management. More recently, industrial textural modification chemistry has started to move into the consumer kitchen. Gluten free and low carb diets are pushing emulsifiers and bulking agents such as maltodextrin, xanthan and guar gum into the home pantry. Industrial textural modification techniques, like sous vide have started to be used by consumers.

With industrial nutritive and textural technologies well on their way into the home kitchen, *how long is it before molecular flavor and nutrients move from industrially produced powders to home production?*

In labs around the world, cultured meats, algae and yeast farms are in advanced research. *How long is it until these technologies reach our basements, kitchens or rooftops?*
How long will is be until leafy greens are considered a poor source of nutrition?

These new technologies have the potential to separate our nutritional intake from our food intake. *Could vital nutrients be better delivered in a Twinkie?*

When one considers that 2/3 of the cost of a cabbage is in shipping and that it contains less than .3% micronutrients, the math is compelling.

> "The BIoT is about to change human experience. Just like the internet. Just like software.
>
> – Connor Dickie, Synbiota

This sounds far fetched today, but are we having the knee jerk reaction of an older generation? It seems to be the case when one adds up the arguments. Chemical natives might very much value more control over the flavor, form, and texture of the foods they eat when combined with improved nutrition and medicine.

These new technologies:

Are a natural extension of the increase in culturing and fermenting that is occurring in cutting edge restaurants and homes.

Leverage base techniques that have been accepted into the food chain. CRISPR-Cas, one of the key technologies has already been implemented in 50% of the yogurt in the world, without complaint.

Can be a cost-effective solution for low volume delivery of the sorts of micronutrients that degrade rapidly in global transport. As global warming and expansion of megacities continue to challenge local food production, this will become a strategic issue.

When combined with personalized medicine, these new food technologies offer an excellent solution for personalized nutrition. As wearables, ingestibles, and implantable devices continue to become mainstream, their snapshots of our gut and organ health will cause an increased focus on personalized nutrition. That focus starts to return us to the holistic view of food and medicine that traditional cultures have, but with a post modern view of nutrition.

PREDICTION

Food and Pharma will collide when it suddenly becomes faster, better and cheaper way to deliver micronutrition and medication through synthetic biology instead of agriculture.

CONCEPT

Foodaceuticals

Improve your mood, avoid disease, lose weight, absorb nutrition using personalized therapeutics.

Compounds that bridge the gap between pharmaceutical and nutraceutical will increasingly be produced in home biolabs, like the Easy Splice Oven. Even if the technology doesn't fully diffuse into the home, it could be delivered to order for a fraction of the cost incurred by major chemical companies today.

Producers of 'Easy Splice Ovens' that create CRISPR-Cas and similar genetically engineered yeasts and e. coli could quite possibly operate outside regulatory frameworks and find themselves competing with big pharma without the risks of actually producing the chemicals, patent infringement or regulatory approval.

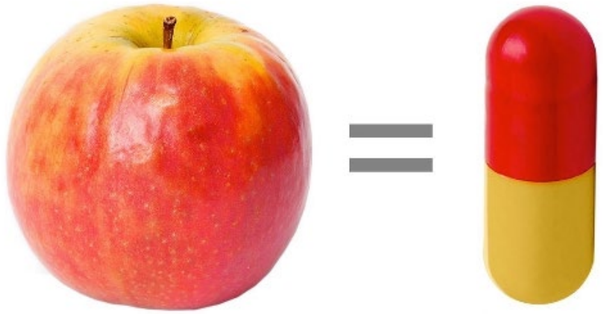


Image Courtesy: Special Projects Agency

Gwendolyn Graff

Creativity Fellow, Innovation, Wrigley

Gwendolyn has worked for the Wrigley Company for 17 years. She has spent a great deal of time in the early development process—ethnography, ideation, focus groups, prototyping, and concept work.

Jon When we look at production technology for CPG foods, what are the big technologies you see coming down the pike in the next number of years?

Gwendolyn I want to go to 3D printing but I kind of don't, because right now it tends to be an extrusion process. You kind of just macerate everything and then extrude it, which loses a lot of your textural components. I think 3D printing will really change the game when we are able to design back in those texture variances.

Jon What are the major technologies that are going to change the way that we eat, the way we deal with nutrition?

Gwendolyn If it ever gets to the point when we're like the Jetsons, and take a pill for your dinner, you have to imagine that value of that pill is very much driven by what it's going to do for your body. It's no longer about a food-eating experience or a texture or anything, it's just about calculated, customized fuel for your body.

Image Courtesy: Special Projects Agency

Image Courtesy: Rob Hanson

Jon Do you have a sense of new crops or material production techniques that are likely to change the food business?

Gwendolyn At SOLID, I am hearing that there is a lot of work with engineering yeast cells to produce compounds that we need or want as our food sources. Microbiology and insects are rapidly coming to the cutting edge of food research. Right now, we think of agriculture as large and land-based. I think we're going to start looking at a lot of other sources.

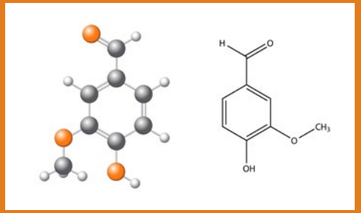
> "We are coming out of this experimental stage where we have been broadening our tool set to reconstruct food in a better way.
>
> – Gwendolyn Graff, Wrigley

Jon So what it seems like we're really talking about is desegregation of texture from nutrition from flavor. That's sort of happened over the last 30 years. Now how do you bring it back together in a way that feels natural and feels comfortable and feels right?

Gwendolyn I happen to be in the food space, so I've been lucky enough to go to molecular gastronomy restaurants, and they've been playing a lot with texture, and deconstructing the food experience. We are coming out of this experimental stage where we have been broadening our tool set to reconstruct food in a better way.

PREDICTION

Flavor concentrates and nutritional additives will replace today's spice rack.



Vanillin molecule

CONCEPT

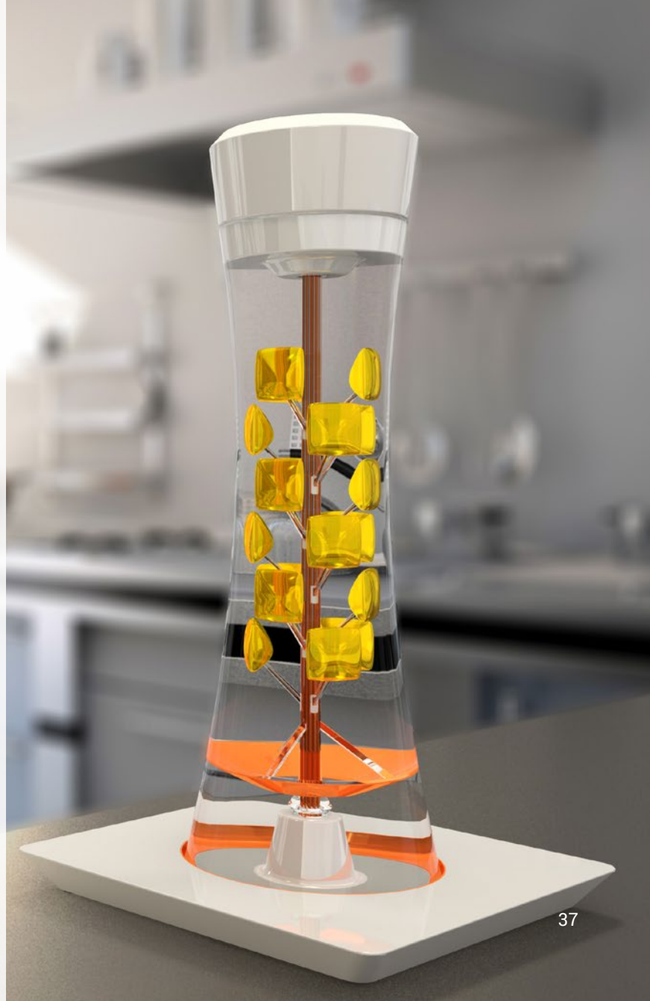
Flavorizer

A device that flavors food could also optimize it for health. It contains herbs/spices as well as flavor cells that are synthesized in the Easy Splice Oven and suspended in oil, water, or alcohol. As it becomes more efficient to produce these flavors in modified yeasts than in the form of plants, we will be able to culture them in our houses and hold them in a smart spice rack that might hold hundreds of molecules that are suspended in oil or alcohol.

A network of microfluidic pumps precisely the right amount of nutrients and spices for the person using the device. The device would access your personal cloud to optimize food flavorings based on health data and personal flavor preferences.

In the case of home cooking the Flavorizer can act as a "home sous chef," working with home cooks manage their kitchens. The Flavorizer facilitates cooking by syncing with the smart kitchen, utilizing recipe information (or verbal/physical cues), monitoring freshness and inventory of spices, and preventing over-seasoning or clumping of spices.

Image Courtesy: Special Projects Agency



INNOVATOR INTERVIEW

Connor Dickie

Founder, Synbiota

Connor co-founded Synbiota Inc. to accelerate biotechnology R&D. Synbiota is a rapid prototyping software/wetware platform for synthetic biology that puts the power of life into the hands of enthusiasts and researchers around the globe. Connor is an alumnus of the MIT Media Lab where he created context-sensitive and attention-aware computers that have since been commercialized by Samsung. Connor is an alumnus of Mozilla's WebFWD program, and winner of the 2014 SXSWInteractive Accelerator. Connor is also co-founder of DIYBio communities in Toronto and Montreal.

Jon What sorts of things can you make with Synthetic Biology?

Connor Biotechnology allows you to de-couple the molecular product you want from the thing that produces it. So let's say I want citric acid which is the thing that makes oranges taste like oranges. I might not be able to grow that in my backyard, but what I could do, is take that genetic code that produces that citric acid and put it into another organism that would readily grow in my environment. For example, you could put it inside yeast. You could then grow the yeast in a little bioreactor in your kitchen and then turn a little faucet and get nice, pure citric acid out of that.

Image Courtsey: Special Projects Agency

> "We can shift away from the world built for the industrial revolution into the world of the bio-digital revolution by decoupling the things that we need from the organisms that produce them.
>
> – Connor Dickie, Synbiota

Image Courtesy: Special Projects Agency

Biotechnology and DNA are computer code. I could then change the code of that same yeast in that same bioreactor tomorrow to produce a different product. Grow that, turn the tap, and get my other product.

Those products can be anything biological. So it could be medicine for example. Right now we get medicine from large companies, you go to a pharmacy and get it. I think there is a real possibility that it would be possible to download medicine where you would have a device in your house that might look like a bread machine. What it does is connects to the internet, downloads DNA code as a text file (a DNA code looks like any other kind of computer code except it is As, Cs, Gs, and Ts.)

Jon The current hype around synthetic biology makes it sound like science fiction. What needs to happen for the public to accept it?

Connor What if a seven year old kid could genetically engineer cancer medicine producing organisms in his kitchen? It happened a few months ago in Nelson, B.C. which is a hippie community in Canada. That was interesting for us because your back-to-earth communities are often anti-GMOs. We've had quite a bit of success giving people a new perspective by putting the technology in their hands and then they really say, "It isn't so much the technology I'm afraid of; it's the fact that these companies have it and I don't know how it works."

We need to get this technology into all different types of people's hands: artists, designers, students, hackers, mothers, teachers, uncles, everybody, they are going to bring their own perspectives to bear.

I think we saw the same thing happen in computing where in the early days of computing it was big and expensive. The kind of people writing programs were PhDs working for banks or the military or the government.

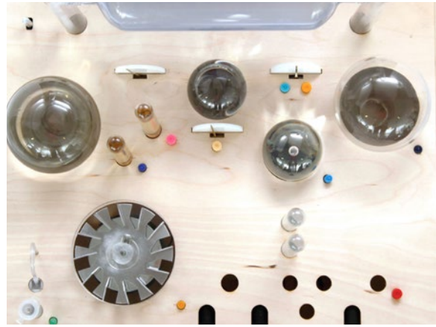


Image Courtsey: Amino

Image Courtsey: Rob Hanson

Now that computers are absolutely ubiquitous there are all types of new art forms that have come in, new ways of expression, people coming up with new types of apps that are making millions of dollars that are coming up with new ways to communicate. I think it is just going to be an absolute flowering really, just like the internet, just like software.

Jon What are the major steps in the technology pipeline that need to occur for the science fiction world of Synthetic Biology to move out ot the maker community and into the general consumer market?

Connor Once you have created your microbe that is producing the compound that you are interested in, you need to get a way to get that compound out of the microbe and purify it

> "There is a real possibility that it would be possible to download medicine where you would have a device in your house that might look like a bread machine. What it does is connects to the internet, downloads DNA code as a text file.
>
> – Connor Dickie, Synbiota

so that it is high-grade. Every biological product requires its own purification process. So, in the case of the Violacein factory kit we have, one of our customers is a graduate student. He came up with a very inexpensive, solvent-based way to extract this research compound, this anti-cancer compound without using thousands of thousands of thousands of dollars' worth of machinery. He's using hundreds of dollars of solvents to do this. As these new low volume techniques diffuse, we will see a range of consumer applications.

Jon One of the things that fascinates me about engineering bacteria is the ability to regenerate in a very precise way things that would typically degrade. For example, we might repair concrete in a foundation with the injection of an engineered bacteria. What does this change about our world?

Connor Creating equipment that improves over time, much like a well managed garden, might allow you to get more money today to build something that is even more incredible. These new biotechnologies are active systems that are alive, and regenerating, and consistently and reliably doing useful work for you. If you can build that into your building, structure, vehicle, or device, you know that thing is going to last a really long time. You are able to amortize the cost over that much longer time.

Biotech additives create new opportunities to defer, change, or delete costs. I think right now there is discussion on America's deteriorating road infrastructure, and how people aren't allocating the funds to bring that back up to speed. Today, a big truck and road crew have to visit the failure site and pour concrete that comes from a big concrete factory that produces waste. You could delete whole process by just putting a biological on there and having that take care of it. You don't need those large infrastructures, which could mean that maybe we could think about more seriously building structures in very remote areas like the moon or something like that.

PREDICTION

Synthetic biology will rapidly consumerize. Chemical, molecular-scale manufacturing will start to occur in the home.

CONCEPT

Easy Splice Oven

The Easy Splice Oven allows consumers to program simple organisms, such as e. coli and yeast to produce almost any organic material. This DNA-driven molecular factory could be used to provide medicines, flavors, nutrients, and even staple goods like milk or egg protein to the home, without the need for the industries and infrastructure that exist to support current methods. These 'Labs In A Box' could likely be software upgraded to produce a range of drugs, if provided the right stock ingredients.

This device would be supported by a file hub for biologicals, where consumers could exchange and improve genetic "recipes". A home bioreactor, much like that used for beer and vinegar production would allow growth and processing steps to occur; after a desirable organism has been developed, solvents that are either ordered in or produced by the Oven would simplify the production process.

A similar, or perhaps the same, system could be used to aid home repair. For instance, a home robot might inject calcium loving bacteria into a failing concrete wall to repair it (See Robo Roach, p. 57)

Image Courtsey: Amino

SCENARIO 3

The Internet of Life

The Internet and IoT are extensions of the physical, social, psychological, and intellectual function of humans. Of our conscious experience.

In the next 15 years, as manufacturing continues its battle for size reduction, organic manufacturing will start to occur en masse, driving production at the molecular level. New innovation will increasingly be about extending and enhancing the chemical sensing and function of our bodies. Of our unconscious experience.

In the electronic age, information was delivered through copper. As bioelectronics drives the next wave of innovation, information will be increasingly delivered and actuated through chemistry. A new sort of bio-logistics. The electronic age was an extension of our central nervous system, providing us with a vision of the world beyond our sight. The dawning biotechnology age will become an extension our lymphatic systems, silently surveying, cleaning and managing the relationship between our bodies and our environment.

This new model of sensory experience will be driven by chemical sensing, communication, and networks that the IoT is naturally pushing toward. Because of the complexity and local, low power nature of these systems, many of them will be emergent networks, much more like life than a domain-based topology.

Survival is the ultimate motivator. As global society continues to urbanize and enter the money economy, the demand for healthcare as a human right will continue to grow. The current developed world health system, with its trauma-focus, million dollar scanners, and billion dollar drug research programs will not be able to scale. A new paradigm will have to evolve, and quickly.

New sensors and delivery devices, we will enable individuals to manage their wellbeing in realtime. We have seen consumer lab tests grow from just a few a decade ago to hundreds today, with order of magnitude cost reductions. As this testing becomes less invasive, lower cost, and faster, it will upend pharmaceutical production and chronic care.

Open source allowed computing to leave the ivory tower. Similarly, synthetic biology will rapidly be pushed down to ground level as labs-in-a-box drop below the $2,000 mark. Suddenly, these technologies will appear in the garages of the families that need them most.

Like music, DNA is a code without encryption. Unlike music, it is difficult to encrypt. The drug, research, and medical services infrastructure will likely attempt to block synthetic biology at home, much as media companies attempted to slow the internet. If this radical transition isn't handled well, it will pit the world's second largest industry, healthcare, against its consumers as the industry tries to protect its IP. Inevitably, big pharma will lose. We have already seen countries like India, Brazil and Thailand buck the system. What happens when consumers start ignoring the law as they attempt to save their lives? It is entirely conceivable that populous, developing nations with weak intellectual property systems will leverage open source healthcare and take leadership positions in medical research and treatment.

> "After three thousand years of explosion, by means of fragmentary and mechanical technologies, the Western world is imploding.
>
> – McLuhan, Understanding Media

Fotini Markopoulou

Co-Founder, Team Turquoise

Fotini Markopoulou is a theoretical physicist and hardware tech designer. Team Turquoise is a wearable tech company that uses research in psycho-physiology, how mind and body affect one-another, to create technology that changes how we perceive, feel, and behave.

Jon How did Doppel come to be?

Fotini We were doing quite a lot of research and experiments in psychophysiology, which is an experimental psychology that studies the roots of emotions in your body. A lot of what you feel is actually in your body; it doesn't happen just in your mind. A classic question would be: is your heart pounding because you're scared or are you scared because your heart is pounding? Our body is a complex set of sensors and can process the data and make it into a story; that is what we are really researching: how your body makes what happens around you into a story, and how you can change the story.

Jon When I think of the entire history of commercial computing, control has meant a completely different thing than what you're envisioning...

Fotini I guess my view of computing is about you more fully controlling your own experience and the machine being a tool to do this. This control needs to be very subtle and gentle, otherwise you will become the machine. Technology should amplify our humanity.

Image Courtsey: Special Projects Agency

Image Courtsey: Rob Hanson

Jon So what does this future look like? What sorts of devices would we see, or what would you imagine?

Fotini Wearable devices will have a much more intimate relationship with our bodies. Doppel, for example, doesn't have a screen, it doesn't have buttons. It is very much apart of yourself. It's not a phone that you somehow attached to your body, it is an extension of your body. The body with a little bit of technology on it, or at least technology that feels like just a little bit of technology.

> "A lot of what you feel is actually in your body; it doesn't happen just in your mind. A classic question would be: is your heart pounding because you're scared or are you scared because your heart is pounding?
>
> – Fotini Markopoulou, Team Turquoise

Personal Ecology

There are approaching 8 billion people on the planet, at 1 trillion bacteria per capita. That's 8e+21 microbes of several thousand types that will be modeled, tracked and managed. Today, something like 2% of manufactured objects are tracked. What opportunities could occur when 2% of human hosted bacteria are tracked and modeled in realtime? And what happens when this model is analyzed in combination with environmental sensing?

Tracking human hosted bacteria will be a priority for healthcare product developers because their populations respond in near realtime to our organ health, hormone levels, some cancers, infection, inflammation, and the behavior of other parasitic organisms in our bodies. Much of the input/sensing will be physiological in nature. Most of this will be filtered by agents and be chemical, decreasing the need for what we traditionally imagine as an interface.

We will potentially develop hundreds of synthetic organisms that produce and distribute chemical payload to manage them. Many of these will be developed as highly personalized, heterogenous therapies. It will be technologically feasible for many of these to be produced in the home. As this occurs, the managed release therapies will be delivered proactively or extremely early in the disease process, enabling them to be much milder, along the lines of taking Vitamin C at the onset of a cold, rather than chemo-radiation after brain surgery. Many of these therapies or their chemical precursors will be delivered to the home through a cool chain that goes from the lab to the house, or by Easy Splice Ovens.

Increasingly, environmental sensing will enable us to understand the chemical nature of the world around us; it will simultaneously allow us to better understand the environmental impact of our world on our health. Our digital and bioelectric systems will build increasingly rich models of the health impact of the microbial ecosystem that we inhabit in our homes, vehicles and cities. These environmental sensors will become an extension of our lymphatic and endocrine systems, simultaneously providing awareness and health services such as:

- **New mild vaccines**
- **Cognitive and mood enhancement**
- **Realtime optimization of the gut biome**
- **Realtime management of hormone secretion**
- **Realtime allergy management**

Health monitoring and therapy will continue to become more immediate, granular, and personalized. Healthcare will continue to become more holistic with a focus on wellbeing and enhanced cognitive function.

What if you didn't need to monitor your habits to change them? Devices that work both on and in our bodies will increasingly sense and optimize our health and wellbeing.

Today, changing bad habits and incorporating healthy ones into daily life is difficult. Intellectually, we understand that we should eat healthy foods, exercise, and make sure we get sufficient sleep, but we're not always aware that we're not doing those things.

PREDICTION

What if you didn't need to monitor your habits to change them?

In the next 5 years, we will see the rise of emotional interfaces: devices that sense and directly manipulate our body chemistry.

Devices will work both on and in our bodies to sense and optimize our health and wellbeing.

Our challenges with self awareness and self control come about because the tempo and thresholds at which we consciously sense problems are too high for predictive action, too unreliable, or too impacted by environmental factors.

Technologies such as Fitbit, Apple Healthkit and Garmin that are attempting to address these issues. But so far these technologies haven't shown the desired results. The challenge has been that they have not been bundled with effective behavior modification tools. Over the next several years wearables will move along a trajectory of providing a range of noninvasive personal health information including glucometry, blood oxygen, heart rate, skin salinity, and eventually sensing volatile organic compounds and hormone secretion. This will enable realtime, detailed models of personal health.

Health and lifestyle outcomes will improve when theragnostics, systems that provide both diagnostics and therapy, come to the consumer space. Physiological management will occur through realtime sensing and delivery to our nerves, our bloodstream and our digestive tract. As this happens, the dosing and changes will become smaller, more subtle and time/event metered. Healthcare will start to evolve past disease management and into optimizing wellbeing. Healthcare will become a sort of palliative care for the healthy.

PREDICTION

Personalized medicine and health enhancements will be delivered based on realtime sensing.

CONCEPT

Outboard Organ

A new class of wearable that provides biosensing and delivers therapies. The sensor will likely monitor heart rate, blood glucose, blood oxygen, skin temperature/salinity.

The device provides personalized vaccines and maintains heart rate by gently vibrating to adjust it when it gets too high or too low to maintain your desired mood.

Image Courtesy: Special Projects Agency

INNOVATOR INTERVIEW

Joi Ito

Director, MIT Media Lab

Joi Ito is a leading thinker and writer on innovation, global technology policy, and the role of the internet in transforming society in substantial and positive ways. In Japan, he was a founder of Digital Garage, and helped establish and later became CEO of the country's first commercial internet service provider. Ito's honors include Time magazine's "Cyber-Elite" listing in 1997 (at age 31) and selection as one of the "Global Leaders for Tomorrow" by the World Economic Forum (2001). In 2008, BusinessWeek named him one of the "25 Most Influential People on the Web." In 2011, he received the Lifetime Achievement Award from the Oxford Internet Institute.

Joi Synthetic Biology reminds me of the early days of the internet. The internet redefined a lot of fundamental assumptions on how telephone companies thought of circuits or how big computer networks thought of architecture.

New people actually had kind of an advantage because they didn't have to unlearn the old stuff. Stuff is changing so fast that, this isn't strictly true, but it almost feels like it's true; the more you know, the worse off you are. We are constantly finding out that everything we thought was true is actually not the way it works. We used to think that genes were the code for everything, which it turns out through epigenetics and through other ways there's all kinds of metadata around the gene and that you can transfer.

Image Courtesy: Special Projects Agency

> "The more you know, the worse off you are...we are constantly finding out that everything we thought was true is actually not the way it works.
>
> – Joi Ito, MIT

Image Courtesy: Special Projects Agency

What's interesting is now with CRISPR-Cas, I think it was formally published around 2013, that now allows us to edit genes for $30. Just during the period of a Master's students studies, something we knew we couldn't do, suddenly we can do.

Jon How do you see the relationship between man and nature evolving in evolving in the next 20 years?

Joi Over the past 25 years, we have seen massive global urbanization and that will continue to happen. In a city, there are all kinds of things going on at the biological sphere that we currently adapt to after the fact: we change the "thermostat". If you actually understood how the biology worked, you could design a city with, and around, nature rather than in opposition of it. I think the future of architecture, and the future of cities, is going to be a lot more about understanding nature and designing things for that.

Today, if you think about what a city is, a lot of what's important in a city is the things that live in the city: they're human beings. You have more microbes in a human being, trillions of them, than there are human cells and human beings are essential in a city. In a city, there are all kinds of things going on at the biological sphere that we currently kind of adapt to after the fact.

Whether you're talking about honey bees or microbes, you could design a city with and around nature rather than in opposition of nature. That requires a certain level of modeling, a certain level of computation, whether you're talking about the shape of the structure, the materials that you use, or the way that you run transportation.

I think the problem in the past is we've done as much as we can to shield cities from nature in these little bubbles, and then try to pretend it wasn't there, but it's actually the whole reason why we're there. As we build better better models of our bodies and our environment, the invisible relationships between ourselves and our environment will become much more clear.

Jon What exciting, unexpected paths do you see in the bio-space?

Image Courtsey: Shawn Caza

Image Courtesy: Rob Hanson

Joi We have this thing called city farm and what we do there is is aeroponics and hydroponics. It turns out by changing slightly the light or the nutrient levels; you can fundamentally change things like the size, the color, the taste, the nutrients. It turns out even more than the DNA, the environment in which the plant is grown has more effect on the fundamental things that matter which is nutrition and growth.

DNA still is important, we're collaborating with Howard Shapiro who is the chief scientist at Mars. He has a wonderful project called the African Orphan Crops Project where he's sequencing all these crop varietals. The cool thing that he's doing is, because Africa and Europe don't like GMOs, working with the local academics and farmers that know breeding, giving them access to all of the state-of-the-art gene sequencing. They can understand what

"

As we build better better models of our bodies and our environment, the invisible relationships between ourselves and our environment will become much more clear.

– Joi Ito, MIT Media Lab

we think this is part of the genome that's going to increase the nutrients, to help with cognitive development, or what we think helps with drought robustness. Then they work together and think about how can we use traditional breeding to do the same thing as GMO techniques. We find solutions designed outside without any local content almost obviously don't work.

Jon How are biology and computing starting to converge?.

Joi We've got Marvin Minsky and the whole A.I. crowd. You've got people like George Church saying "why do A.I. on silicon, why not do it in the brain?" Then there's other people saying well maybe the brain and circuits should be connected, or maybe there should be a better user interface between A.I. and human beings. So Karthik Dinakar is working on what we're calling human in the loop computation, which is putting the human inside the training loop of A.I. So we've got this whole spectrum of pure A.I. and we work with Carnegie Mellon and the rest of MIT on that; all the way up to George Church and making our brains smarter and everything in between.

PREDICTION

To perform tasks in air gaps without removing walls it will be cheaper and more effective to add outboard intelligence and sensing into lower organisms than to engineer mechanics that are superior to nature.

CONCEPT

Bio-Bots

A Biobot is a lower animal, like a cockroach, that has been outfitted with outboard cognitive support that controls its actions. This outboard package might also have chemical sensor and load capacity, much like a micro dumptruck, depositing material like bacterial fillers for cracks in concrete where they are needed.

Image Courtsey: Special Projects Agency

Jon What key changes changes need to occur for the type of technology, bio-engineering that you're talking about, to occur in scale?

Joi I'm an internet guy so I look at things like the internet. The internet started working really well because we unbundled the layers. You could continue to iterate making the fiber more efficient, you could iterate on the IP and the BGP protocol and each layer could be worked on without really disrupting the other layers. You didn't have to know about the other layers to contribute at your layer and I think what's key.

You can have people working on new technologies for doing the gene editing without affecting the next layer, which is to take and identify the genetic blocks, and then another layer which is a design tool for genetic blocks. So you unbundle the pieces and create APIs between them. An example would be if you looked at Ruby or some programming language. It's all modularized in a really good way.

PREDICTION

The miniaturization of electronics will lead to ingestible devices that detect what your body needs and deliver personalized medicine in realtime.

CONCEPT

In-test-able

The In-Test-Able is an ingestible device that provides and a daily body scan and event/time released medicine.

The main body passes through the digestive tract.

A time release device attaches to the intestinal wall, and monitors gut bacteria, chemistry and pH, calorie and nutrient intake in realtime.

It secretes what your body needs, when your body needs it to enhance and optimize health, mood, and cognitive ability.

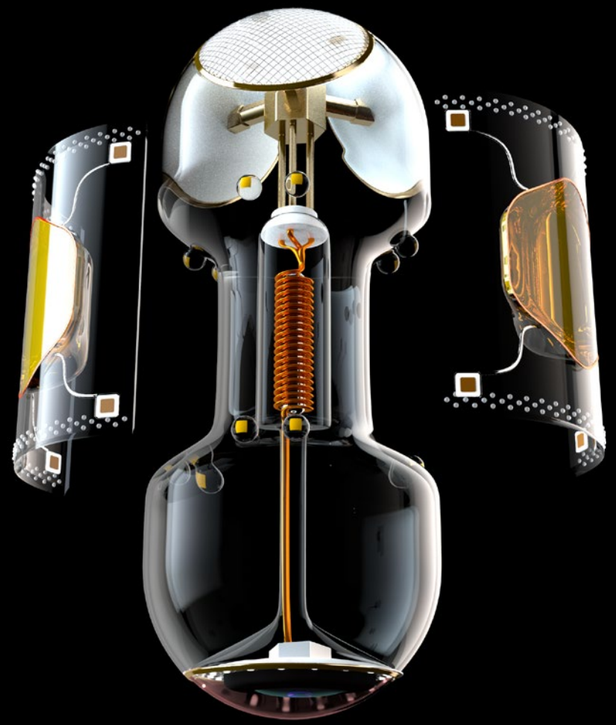


Image Courtsey: Special Projects Agency

INNOVATOR INTERVIEW

Abe Gong

Human Centered Data Scientist

Abe Gong is fascinated by the intersection of data science, behavior change, and the Internet of Things. Previous roles include co-founder of Metta, the first data scientist at Jawbone, and lead data scientist at Massive Health.

Jon What technologies in the wearables and IoT are most exciting you?

Abe One of the trends that I see in IoT is hyper personalization. Not just building an app that works for a specific demographic, but having wearables, smart homes and systems that know about you in particular. They know you. They know your habits. They know where you are in your life. That is, I think, the precursor to much better software. A very personalized fit for exactly you. … As you get to things like heart rate variability or glucose, those start to be tied very directly to specific medical conditions.

Jon What technologies do you feel will change about the way we interact with the world around us?

Abe We are at a moment right now where there is a lot laboratory work, like academic studies, that show that you can influence people's behavior in one way or another. There is also a bunch of work being done in advertising and marketing that takes that and weaponizes it and uses it to drive revenue. Instead of being applied in the service of a company or government, they are going to be applied in the service of you individually.

Image Courtsey: Special Projects Agency

Image Courtsey: Rob Hanson

Jon What will drive that change?

Abe Much better individual data and more touch points for interacting with people. Your phone is a foot in the door. Smart watches, smart homes, smart car, all of those are places where you can start to have a conversation with that system.

Jon How do you filter out what's got to be an unbelievable amount of noise as all of these systems are bringing content in?

> "The things that have emotional relevance are the things that affect you and your well-being and your sense of self.
>
> – Abe Gong, Human Centered Data Scientist

Abe I think the key really is empathy. When you look at what your mind's emotional system does, it deliberately filters out noise and helps you prioritize the stuff that impacts you. The things that have emotional relevance are the things that affect you and your well-being and your sense of self. I think there is this really interesting thing happening in the data ecosystem right now, where we're starting in a very, very early type of way, to create that same type of capability.

PREDICTION

Pervasive sensing in the home will lead to new augmented reality overlays onto it, helping people remember where they put things and were aware of tripping hazards.

CONCEPT

Bright Lite

The Bright Lite is the sixth sense for your home. This "eye in the sky" device screws into existing sockets and monitors what is going on in your environment.

If you want to find something, Bright Lite remembers and uses its laser pointer to show you where is was last seen. In addition to memory augmentation, Bright Lite augments your other senses.

If you're walking down the stairs at night it can turn on, or highlight, a trip hazard such as a sleeping pet on the stairs. Bright Lite can also identify changes in the environment, such as a spill, and request a Roomba's immediate services.

Image Courtesy: Special Projects Agency

INNOVATOR INTERVIEW

Rob Coneybeer

Co-Founder, Shasta Ventures

At Shasta Ventures, the Sand Hill Road firm he co-founded in 2004, Rob focuses on hardware and mobile startups. Rob started his career working in the Astro Space division of Martin Marietta, where he helped build the first EchoStar spacecraft.

> We need to be considering the required life of hardware products.
>
> – Rob Coneybeer, Shasta Ventures

Jon What do you see as the major changes in in the startup hardware space today?

Rob Planning for obsolescence is the foundation of Silicon Valley today. As IoT products deliver networked software to consumer goods with a longer life, we need to be considering the required life of hardware products first and use software to expand relationships with customers that encourage the purchase of a network of products over time.

Jon What technology areas are most exciting you now?

Abe I'm particularly excited about robotics and virtual reality finally coming out of the trough of disillusionment and into mass adoption through recent advances in machine vision and sensing are riding efficiency gains in computation and sensing. This is a natural extension of the human desire to see, feel, and manipulate worlds that are remote to us. We can expect that technology to democratize in the foreseeable future. In the near future, improved robotic grasp routines, simplified programming interfaces and user safety features will radically increase the number of applications where robots can be used. In the longer term, one could imagine connecting the controls and feedback mechanisms for robotics to our nerves directly.

Image Courtsey: Rob Coneybeer

PREDICTION

Management what is happening in air gaps of buildings will be one ofthe early high-value consumer applications for the IoT, detecting maintenance and repair needs before damage is done.

CONCEPT

In-Sight Molly Bolt

The In-Sight Molly Bolt does double duty. It can be used as a picture hook or to mount cabinets. It is also a home sensor package that penetrates the wall to gather information where it is most important, and hardest to access.

The In-Sight pings a hub with a situation report when an issue is detected. The hub will determine the corrective course of action (schedule a repair, turn off power to that circuit, insert a termite trap) and notify the homeowner of the next steps.

The central core of the Molly Bolt allows BioBots (p. 57) to access the wall and deliver chemical payloads to manage issues in air gaps long before they become major issues.

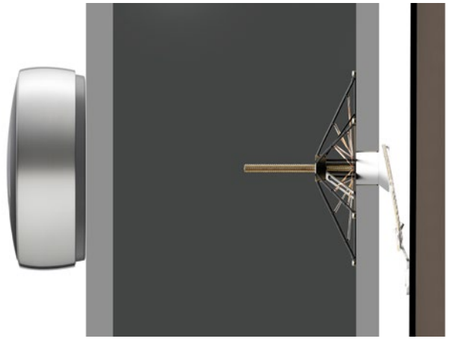


Image Courtsey: Special Projects Agency

Symbiotic Computing

What happens when computers are able to predict the impact of environmental molecules on the molecules in our bodies? Environmental sensing created for the IoT and our peripheral organs will increasingly respond to each other in a reciprocal relationship. For example, home temperatures might automatically adjust based on its occupants' skin temperature, or a vaccine or allergy relief could be delivered proactively based on input from environmental sensors.

Image Courtesy: Team Turquoise

Smart environments are already being built into our homes, managing temperature, lighting, and security. Soon, systems will be incorporated to help manage more complex maintenance and risk, such as mold, termites, and leaks that emerge in the air gaps between walls.

Many of these repairs will be too small to justify opening up the walls. The combination of AI and micro-robotics will become proactive about diagnostics and maintenance. If the cost of AI, computation and sensing continue to drop faster than the cost of material it is likely that these micro-robotic chassis will take some unexpected forms. We will start to see genetically engineered lower life forms with computationally augmented situational awareness and intelligence.

The underlying goal of health is enhanced social, cognitive, physical, and sensory experience. As we start to understand the interaction between our body systems and the environment, healthcare will move beyond a focus on chronic care to wellbeing.

The combination of chemical sensing and micro-robotics create the potential to bridge the systemic relationships between smart environments and the human body, building a model of interaction between the molecules in our environment and those in our bodies. For the first time, we will have a realtime awareness of ourselves and our ecosystem at a microbial level, and an ability to manage both.

Because the systems that are working in our homes and in our bodies will be invisible to or hidden from us, we will need displays that overlay data onto the environment. As augmented reality starts to enter the world of practicality, it will take on unexpected forms. These won't be in glasses or smart phones. They will be built into our home electronics. They will do more than tell us about health risks in our homes of course, they will become the display systems for pervasive sensing in our home, a sort of Google for life.

> "As we build better models of our bodies and our environment, the invisible relationships between ourselves and our environment will become much more clear.
>
> – Joi Ito, Director, MIT Media Lab

CONCLUSION

Pandora's Box is Open

As organic sensing and organic chemistry enter the IoT, the same AI advances that drive it will naturally enable new BIoT applications. The BIoT represents an evolutionary–scale technological advance for mankind.

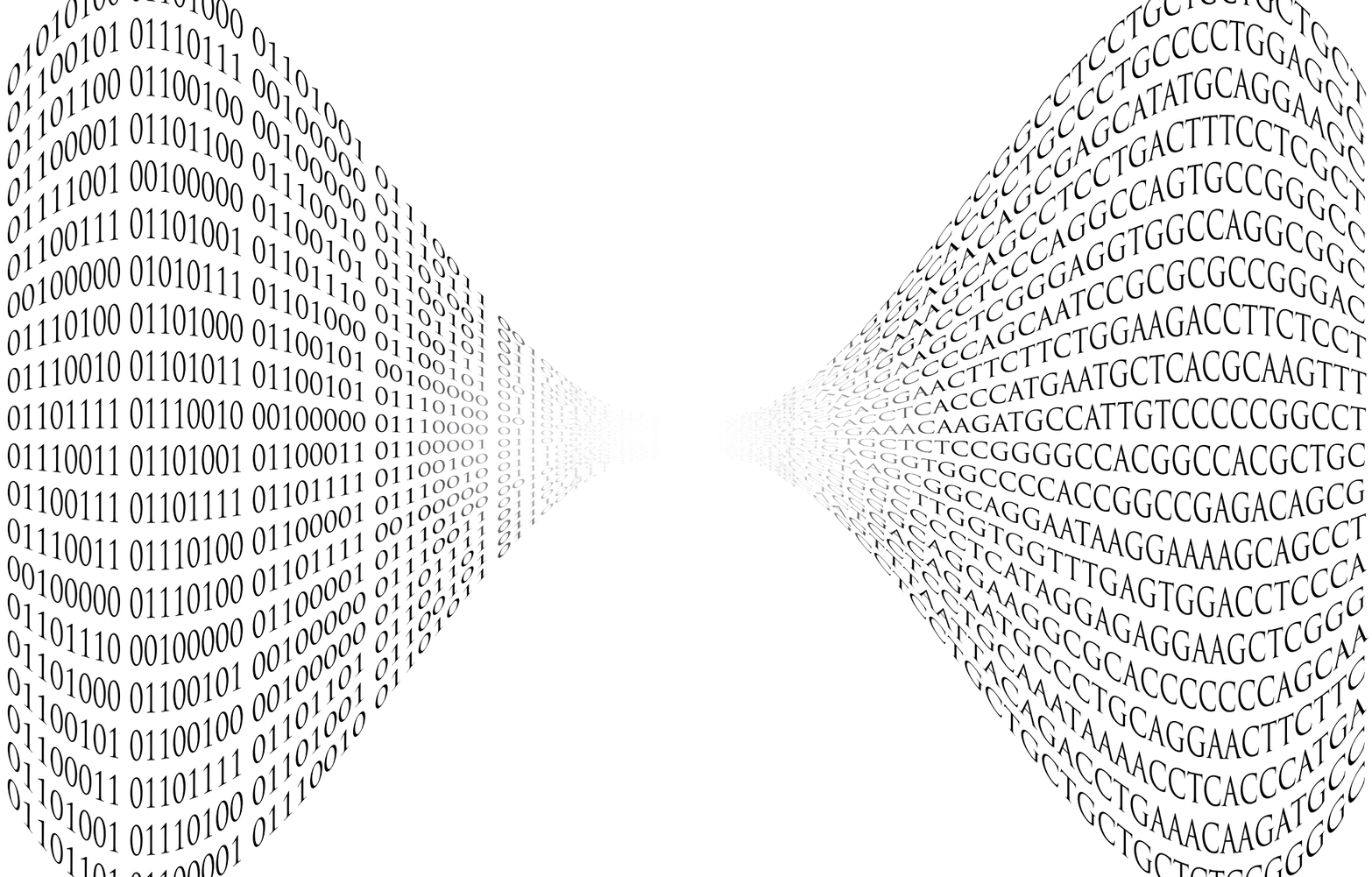
The impact will be seismic. It will grow at tremendous speed because it sits on top of existing web and IoT technologies.

As biology meets computing, we are going to start to unbundle the technology of life. The layered nature of the BIoT technology stack will allow innovation throughout the stack to happen independently. This was a critical factor in the growth of the web because it allowed technologists to focus on specialized areas and know that their technology would play well with others.

A number of stealth organizations are already in advanced stages of product development with early application, network and operating systems. As a global society we are completely unprepared for the challenges, risks, and opportunities BIoT represents.

> . . .you unbundle the pieces and create APIs between them. An example would be if you looked at Ruby or some programming language. It's all modularized in a really good way.
>
> – Joi Ito, on DNA as a programming language

DNA is, by its nature, unencrypted and available to all. The marketplace advantage will be similar to the open source community.



Camouflage, speed, standards and code repositories will be the points of control.

Challenges

1.Network Management/Security

As computing moves across multiple devices and into DNA, application and search topology will start to become incredibly complex. This will lead to a hypercompartmentalization of certain technologies and areas of knowledge. No individual will understand the whole system. In a speed-driven competitive environment, robots and AI will be more accurate and faster at performing the required repetitive tasks than people, thus they will be driven by machines.

These machines will need to manage a patchwork of emergent networks. Power requirements and multiple generations of devices will force a new approach to network architecture and management. When these complex networks are being woven into the fabric of everyday life at the consumer level, it will be impossible to introduce whole new systems every two years. These networks won't resemble the traditional hub and spoke or mesh topologies. They will seem chaotic to anyone besides their creator.

These sorts of cobbled together systems are perfect targets for attack. When their computational power is multiplied by millions of households across multiple countries, they represent an asset that is difficult to both defend and shut down.

Because of the permeable nature of the system, multiple generations of AI will need to manage networking and security both in a concerted manner and with a high level of autonomy on individual devices.

How do we get all systems talking to each other reliably? Who's making sure operations are functional? What happens when upgrades are introduced into the systems and how do they filter down? How do security and network APIs work across devices with radically differing operating layers and power requirements?

2.Interface

No one has begun to talk seriously about how to interact with all of the new applications that the IoT and the BIoT enable. Since the advent of the personal computer the big challenge has been how to help people become more computer literate. As the IoT and BIoT become more prevalent, the challenge will be how to make computers more human literate.

The purpose of good interface design is to help people focus on what's important. Today that means responding to one or two alerts at a time. We can still rely on visual and auditory cues to interact with information. When there are the potentially thousands of alerts in any given minute, what will that mean for interface design and interaction?

The interface for the services that sit atop the BIoT will increasingly look like the global operations center at a telecommunications company instead of a mobile app, and will, like the networks that power them, be too complex for an untrained human to look at and understand.

To experience and manage the sheer number of network-driven events, we will be required to become more cyborg in some ways. Systems will begin to interact directly with our preconsciousness, impacting cognition, emotional experience, focus and self awareness, without a direct awareness of any of it. These symbiotic interfaces will power network applications that empathize with our circumstances and respond proactively, based on the data available to them.

As information becomes more complex, new feedback mechanisms will be necessary to interact not only with our eyes and ears, but with our guts. Our chemical senses, our sense of smell, our sense of taste, and the enteric nervous system will increasingly become the pathways for interaction. Unlike our eyes and ears, they are meant to monitor and manage thousands of situations simultaneously and manage realtime chemical production, pharmaceutical uptake and hormone secretion in our bodies. This means that the separation of information from objects will extend beyond bacteria, drones and materials. It will literally extend to us. Human evolution will leap forward.

Some key questions need to be addressed:

Who is guiding the journey?

Already today, most of the internet is dark to consumers. Google decides what people see. It's unlikely that will change. What blindspots or biases will defects in the code and stakeholder interest create in the internet of life? Who will determine priorities and access?

What is real when everything is managed?

It's one thing for a service provider to shutdown your cable box. It's quite another to have a service provider shut down your health, or modify your consciousness.

What is the consumer experience of Enterprise-level IT?

As our digital experience of the world continues to move both into our bodies and into molecules on the other side of the planet, who is in control of what we are aware of, what we search for, and how intensely we experience the results?

Who is responsible for freak occurrences in emergent systems?

When consumers start to control thousands or millions of IP addresses, the challenges become similar to those faced by enterprises and governments. If today's big cyber-security risk is loss of reputation or identity theft, how will we respond when life and perception of reality are impacted by cybercriminals or service outages? How do individuals maintain control in an unregulated environment?

What is human experience?

The nooks and crannies of this new world will be managed by code, much as markets are managed by trading algorithms today. In whose interest do these algorithms act and who is responsible for their actions?

Parting Thoughts

The internet of life, like life, will be self organizing and will evolve from vicious cannibalistic competition. If we are truly as gods, how will we take responsibility for this new thing? How do we maintain civility in a jungle that evolves faster than we can think? I surely don't have the answers, but I also have faith that they will come…because this the next Google-scale opportunity.

So, what is the opportunity for the rest of us? We are in this age of quantification where the minutiae of our lives are becoming measured and crunched but what is the end goal? To turn San Francisco into SimCity? The end goal of the quantified life is about more than keeping score.

The Internet of Life is about better living through chemistry.

Thank you.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