RAMESH RASKAR: And has done just terrific, terrific amount of work. He was also [INAUDIBLE] program manager where he led the effort that we have studied in the class, the origami lens and many interesting projects. So here, today's going to work on something that hopefully get us thinking.

It's just at the right time. It's the middle of a semester, and we have learned about a lot of ideas. And all of us enjoy talking to Ravi about where the field is going and how we can classify and understand the field itself of computational imaging and computational camera better. So looking forward to it.

RAVI ATHALE: Thank you. Thanks, Ramesh. It's a pleasure to come here and talk about this thing that all of us love so much-- cameras. And this, I worked a lot on this type of camera, as we cannot picture.

So anyway, I sent the slides to Ramesh ahead of time to make sure. I didn't know how to calibrate where to go, but he said that these slides are just perfect, so I trust his judgment. And I wanted not just the seminar or lecture, but a lot more interactive. So we can go through some of these very quickly if I see from your faces that, why is he telling us these things, but be as it may.

So history of camera-- I think this was meant more for general audience, so I really focused a lot on history and how we are at a dramatic breakpoint, how that breakpoint is likely to impact the future, and things like that. So interesting historical milestones that you may or may not have covered in the class. Let's go with that.

But this is one thing, of course, now, if you need to be told about this, you all are carrying cameras. If you lived in London, you probably got photographed about 30 to 40 times during a typical workday as you stepped outside, and all these things. I just wanted to point out to-- I don't know how many of you will know what that image is.

In order to know what that image is, you need to focus on the date, April 19, 1995. That date has a special significance. It was the Oklahoma City bombing, and this is the truck. This is the Ryder truck that carried the bomb. And this is a picture from a security camera in the bank across the street.

And this image has been used by many, many people to justify the work on high dynamic imaging. Everything inside is completely underexposed. Everything outside is completely overexposed.

As a result, this image, by itself, is pretty much useless. So things come in two sizes-- too big and too small. Similarly, this is the tape.

This is a very interesting thing, and I also had another image of, somewhere in Iraq, an IED going off and blowing up, and some person holding the cell phone. And so I'm sure you're aware that, over the last few years, any significant news [INAUDIBLE] that happened in most places around the world, the first reports and the first images to come out of that were cell phone cameras. So everybody is a reporter.

So anyway, one of the interesting things is this business about natural observation, gaps in the leaves projecting images of a partial solar eclipse. So our ancestors must have observed these things and said something is going on. So exactly what is going on, and how can we replicate it? How can we understand what's going on over there?

This is another very beautiful photograph. I'm sure you have see waterdrop acting as a lens, forming the image. So just before there was any technology, before there was even a formal modern scientific process, our ancestors, a couple of thousand years ago, since they didn't have the distractions of cable TV and cell phones and all that, they had a lot of time to really very carefully observe nature and observe it over a long period of time from many different angles.

So as an outcome of this was the observation of pinhole images going back several thousand years, and I believe-- at least I understand that this was the first comprehensive study on optics, Alhazen. And this is the drawing of a pinhole camera. I think, Ramesh, you have probably told them about the origin of the word--

RAMESH RASKAR: I have not. Go ahead.

RAVI ATHALE: You have?

RAMESH RASKAR: I have not.

RAVI ATHALE: Oh, you have not? Camera, the literal meaning of the word, is room because the first camera was indeed a room with a hole there, and the image projected back there, so you can trace it or something like that. Now, what is interesting is, fast forward 1,000 years, and the world's largest pinhole camera was constructed in July 2006.

The El Toro Marine Corps Air Station in Irvine was decommissioned. They wanted to preserve it, so they took an airplane hangar, closed the door, and drilled a hole the size of [INAUDIBLE] tennis ball or something. And on the backside, had a photographic film eight stories tall and 1/3 the length of a football field. And here it is.

This is the image of the base upside down projected on the back wall. This is this the photographic emulsion, and there were a lot of numbers as to how many gallons of developer solution they needed and basically throw it over a barrel and take a broom and spread it over and develop it. And I don't know where that image is now. I think it is in California, some art museum somewhere in Los Angeles.

The point of that is, over 1,000 years, and exactly the same operating principle. It's just a room, except a much, much larger room, and taking a picture of a much, much larger area.

STUDENT: Right, you do make a good point there. They also [INAUDIBLE] how much time they had to spend to make the [INAUDIBLE].

RAMESH RASKAR: Yes, indeed.

RAVI ATHALE: The first optical instrument are spectacles, and I think that really, the point-- this is an interesting point. Spectacles are glasses. It really is a mechanical packaging solution. So people realize that having these specifically shaped lenses improves your vision, but how do you do that? How do you make it convenient for you to wear?

So people realize you have two years, and they're shaped in this manner. And there is the bridge of the nose, so 3 point support like this. Of course, then there were all the elaborations of the [INAUDIBLE] glasses sitting or the monocle that you can screw into your eye. But this is basically-- 1270 is the-- taking these optical phenomena and constructing a useful instrument that can be portable, and that is used.

Beyond that, almost a 300 year gap between a single lens optical instrument and a compound optical instrument-- microscope and then telescope and everything. You might have known this the 400th anniversary of the Galilean telescope revolution, and this is the diagram [INAUDIBLE] multiple lenses.

So going forward, the next history is photography. This is the first photograph ever by Niepce, 1827, and it's basically the [INAUDIBLE] sensitive media in various forms, and it just evolved. One of the big milestone was this sort of glass. It was coated in a paper and rolled in other things.

So there's another tidbit-- Eastman Kodak. What does Kodak mean? Anybody knows? Eastman wanted a word that was a very crisp word, and that was very positive, forward-leaning kind of a word. And so apparently, Kodak is the sound that the shutter made when you push the button.

[STUDENTS LAUGHING]

So it was not George Eastman and his colleague Kodak Eastman Kodak was named after. But the slogan was, you push the button, and we do the rest. And I think $1 Brownie camera-- if you put it in historical context, that was around the same time when Model-T, maybe a few years earlier, 10, 15 years earlier. But it's taking essentially really high technology and using some innovation to bring it down to masses, so everybody can use it.

So you can say that Model-T and the Brownie camera was the first age of modern consumer technological culture. More than three-color color emulsion, kodachrome stacked with doping and everything, and Polaroid instant camera. Of course, in 1945, the definition of instant was a little bit different. 30 seconds to two minutes was considered to be instant.

And this, I was intrigued. This, of course, I found it on Wikipedia. But Maxwell, whom we don't normally associate with doing experimental work, but this was the color photograph.

RAMESH RASKAR: Do you know how it was captured?

RAVI ATHALE: At three separate exposures, and then stack them. Three separate films through three separate filters.

RAMESH RASKAR: But how did he put them together?

RAVI ATHALE: I guess outlined it by hand.

RAMESH RASKAR: After developing it?

RAVI ATHALE: Yeah. And of course, Abraham Lincoln was the first president to be photographed, and lots of beautiful photographs of Civil War.

RAMESH RASKAR: The photograph looks still crisp.

RAVI ATHALE: Yeah. I don't know. I don't if it was subsequently touched up.

STUDENT: They used the light field camera.

[STUDENTS LAUGHING]

RAMESH RASKAR: Actually, light field camera was invented back in 1908.

RAVI ATHALE: Yeah.

STUDENT: It looks like it's a long exposure maybe because the trees in the background are kind of--

RAVI ATHALE: Yes.

[INTERPOSING VOICES]

RAVI ATHALE: I think--

STUDENT: Using a pinhole.

RAVI ATHALE: All exposures were long. But-- Another historic milestone that captured [INAUDIBLE] display that [INAUDIBLE] so mechanical scanning and all kinds of other things, CCD. Just, I gave this seminar about a month and a half ago, and two weeks later, the CCD Nobel Prize was announced.

And I don't know-- many of you are probably aware of the controversy whether these people really deserve the Nobel Prize or not because they were working on shift registered memory. And it was somebody else who said, hey, it's light sensitive. Anyway, but most of these things, there is always a controversy about including MRI and all kinds of other things.

But this is kind of interesting. Here. Look at this, the first Fairchild camera. So I think 88 pounds. 0.01 megapixels, 23 seconds. And actually, if you look at the date, December '75. That's not that far back.

RAMESH RASKAR: Yeah.

RAVI ATHALE: That's not that far back at all. Then the subsequent digital camera [INAUDIBLE] Sony [INAUDIBLE], quarter megapixel DCS 100, 1 megapixel $20,000. And '97 was the first transmission of picture from cell phone and cell phone camera.

And this last one is very interesting. Very recently, Kodak stopped production of kodachrome film, so if anybody has film cameras, well, you better start stocking up on old film. And 2006, the 10 megapixel cell phone.

I think with this camera, pixel cell phone cameras and all that, instead of a cell phone with a camera, this is a camera with a cell phone. So the bulk of it is probably the optics and everything else. Optics, mostly, that goes with it.

You have heard of Moore's law? There is something called Kennedy's law. Empirical observation. How many pixels per dollar? And that's of course, a large scale, and this is a linear scale in years.

From this DCS 460, 100 pixels per dollar, to all the way here. And we will probably-- I don't know, this is still an old girl. A megapixel camera, I think $5, and I think the goal of many of these companies is megapixel camera for a buck. Everything-- the lens, the focal plane array, the PC board, and everything ready to plug in.

RAMESH RASKAR: With a wafer level cameras.

RAVI ATHALE: With the wafer level cameras.

RAMESH RASKAR: It's already about $1.

RAVI ATHALE: Yeah.

RAMESH RASKAR: Less than $1.

RAVI ATHALE: So megapixel per dollar, so it's already out there somewhere. And this is the picture gallery, so the [INAUDIBLE] 100, Samsung. This is the Omnivision's focal plane array, 2.1 by 2.3 millimeters. And this is a very interesting thing.

[INTERPOSING VOICES]

For endoscopy, video endoscopy, 1.8 millimeter diameter includes lens, the focal plane, the cable for sending power, sending the signals back. Not great resolution, 326 by 382, but if something needs to be stuck inside your body, smaller the better, and 1.8 millimeter is definitely, definitely nice.

This chip is the one that's used in the pill camera that you swallow to image your insides. I thought of something-- that imaging case study, studying the inner space versus studying the outer space. So the camera pill and the Hubble Space Telescope.

RAMESH RASKAR: Both are shaped like a pill.

RAVI ATHALE: (LAUGHING) Both are shaped like a pill.

RAMESH RASKAR: Just a little.

RAVI ATHALE: Both are shaped like a pill in the sense this was actually in the montage program that I started at DARPA. That was one of the motivations that, over the past 30, 40 years, the displays have become thinner, from bulky CRTs to thin, flat panel displays. But the cameras, the aspect ratio of the cameras, have not changed in the past however many thousand years. They are always tube like, and so the goal was, can you squash the cameras.

Can you make a camera that is five millimeters thick, but the effective focal length is 50 millimeters, and the light gathering power also [INAUDIBLE]? And there are various tricks that you can play. The origami lens that you probably studied is one of the examples. A multi aperture is another example.

But one of the things about-- and I'm not sure, in this presentation, there are the technical details or specifications. But it's very interesting, if you look at the specifications of, say, Hubble, a pill camera, or take one of the modern lithography lenses, I don't think I have a picture of that, but the model lithography lenses are a marvel of technology. That these things-- getting-- you remember how much-- they weigh several thousand pounds.

RAMESH RASKAR: [INAUDIBLE]

RAVI ATHALE: Some obscenely heavy, huge number of elements in this, and cost multiple million dollars. And the reason is that it's absolutely diffraction limited performance over a fairly wide field of view with zero distortion and all the aberrations, everything corrected.

Now, multi-scale images broad, wide, and deep. Now everybody, gigapixel imaging, since the inauguration, it has really taken off. There are so many images like that, having the wide panorama and finding the details over here somewhere. The eagle.

And so can we get here from where we are right now, and in a realistic size, weight, cost thing? Can we get a gigapixel camera? Can we get a 10 or 100 gigapixel camera?

Very wide field of view. Very high resolution. These are some of the challenges that will be addressed, and not doing brute force. So it's an interesting prospect, and it's an interesting direction.

RAMESH RASKAR: But in terms of the cameras that individuals will carry? Or this will be installed, and then you have access to it, so that you can [INAUDIBLE] of interest, you can capture what you want?

RAVI ATHALE: This is kind of an interesting thing. You can imagine an individual, like special operations soldiers, carrying binoculars with the standard binocular form factor that will be equivalent to a gigapixel. But there are no gigapixel displays. Human vision doesn't have the space bandwidth for gigapixel. So within that gigapixel, you should be able to [INAUDIBLE] and zoom in and look at the details.

There is an ongoing DARPA program-- I don't know what phase it is at-- some cognitive technology for warfighters, blah, blah. It was colloquially called Luke's Binoculars. So in *Star Wars,* Luke has these binoculars, and you're looking at it. And it could put a cursor that alien there, or that's that.

It was primarily focused on the processing based on neuromorphic algorithms or something like that. So the idea will be, if you can design the camera or an imaging sensor that can capture a gigapixel worth of information, and if you have this back end, this neuromorphically induced processing, that can cue the soldiers to look here, there, and the soldier can appropriately focus there. In terms of what kind of things that will be really useful for warfighter right now, that could be one of the things.

And then of course, you have platforms at various levels, from micro UAVs with about nine inch wingspan, to Predators to all the [INAUDIBLE] space based imaging. And the field of view, and the pixel resolution requirements, and everything-- it spans all over the space.

So I'm switching gears a little bit, and previous was, you can say, an anecdotal or event based vision of the history. Now, we'll go into a little bit of a technical angle of looking at history. So I think, first, one of the questions-- and this also gets into where we should be headed anyway.

So imaging sensors, or you can say sensors in general, why do we do this? What it is, and why do we do this? So questions we ask, and this is something-- these are very generic questions. And we constantly are asking these questions, who, what, where, when. That's the sensing front end part, and how and why is the analysis and exploration part.

So when you reduce it down to its sense, all we care about is answering these questions. When it comes to using imaging as spatial sensors, not imaging to take photographs of your vacation, where you can view this and recapture the experience. That's a different world, and in some sense, computational photography and computational imaging, that's where-- when I say computational imaging, you are looking at imaging, you are considering that as a spatial sensor.

A spatial sensor means a system that is designed to answer these questions. Identifying various constituent elements in the scene, specifying their location and their time.

Now, within this particular realm, you have two different sensory modalities. One, you can say proximate sensor, and the other is standard sensor. So proximate sensor, I want to know what is the texture of a surface.

I put my hand at the sensor are move around. I say, is it rough or smooth? Is it uniform? What is the granularity? In other words, your sensors are spatially co-located with the object that you are trying to measure.

And the other thing is your sensors are separated by some distance. Now, that standoff is a malleable soft concept. Say, for example, take the magnetic hard drive disk head. So for a magnetic storage, the heads will be floating, I don't know, a few microns or a few hundred nanometers above the disk surface.

So if, when you go to the optical disks, and the optical head is floating two millimeters away from the surface, that's a huge distance. So that's a standoff for writing and reading, whereas a standoff, if you're talking about a Hubble Space Telescope that's looking at the farthest galaxy in the universe, that standoff distance is however many billion light years away.

But the point is, where you're making the measurements is not co-located with what it is that you are trying to measure. If you are doing standoff sensing, it has to involve real propagation. No ifs, ands, or buts. And that's almost contained in the definition of wave motion.

Wave is defined as a phenomenon that carries energy and information over distance without material transport. So that's the difference between a soundwave and wind. Wind will carry leaves with it. Soundwave will not carry leaves with it.

Both involve movement of air molecules, but soundwave is capable of carrying energy and information over a distance without a bulk transport. And then of course, you have the electromagnetic waves, then you have seismic waves, all kinds of waves. But nonetheless, wave motion-- it is at the heart of any kind of a standoff sensing activity.

So when you have wave, and you have standoff distance, you have wave propagation that involves diffraction. And that diffraction essentially strangles the spatial organization of signals. So in other words, this particular scene, there is ambient light that is reflected off your face as individual spots on your face.

And so right there, if I put a photodetector and move it around your face, it can measure the reflectance of the surface. If I move that photodetector over here, and if I put a photographic film or a CCD without any optical element, I'm just going to get basically a uniform exposure. All that spatial organization is lost.

So we effectively, when we are doing the standoff sensing, we have two parts. One, you can call it the source encoding. That is the phenomenology by which the objects in the scene impress information about themselves on the electromagnetic radiation, whether it's by emission or reflection or absorption or scattering. And the full domain of the electromagnetic wavelength, the amplitude and wavelength and polarization and everything, is used to encode that information.

And the other is channel encoding or channel distortion. That is the result of the propagation of that wave between the objects and your entrance pupil, or where you're entering. So these are the two things. So when we say about processing, we are talking about removing the channel distortion or undoing the effects of diffraction.

So what are the components of an imaging sensor? And I'm sure you have done this in this class. So there is the front end element that operates on the electromagnetic wavelength of the optical wafer directly.

Then there is the transduction that takes that electromagnetic energy and transduces it into some other form. In photographic film, it was chemical. In CCDs and CMOS, it's the electrical energy.

And then there is the storage display processing and exploitation. So these are the three stages, and I'm using the [INAUDIBLE]. This color is not that strong, but blue means biology and pink means technology.

So in the pre-prehistoric period, all these elements were biological. The front end element was the optics of your eye. The transduction was your retina, and the subsequent processing going into [INAUDIBLE] went all the way up to the prefrontal cortex. But some recognition or some processing exploitation took place. It was probably before language, so we don't know whether pre-prehistoric primates, and what terms they thought.

So then we come forward to prehistoric and historic period down to cave paintings. So there, the storage and display "technology," in quotes, was introduced. Everything else is still biological, but capturing and storing that experience-- and beyond this prehistoric and historic period, you can imagine the technology getting more sophisticated, but the principle did not change. And it stayed that way through the prehistoric and historic period.

Now, as we go forward to pre-industrial period, and as I said, the optical elements were introduced. So the optics of the eye, or the front end element of the entire sensing chain, was augmented by technology. And what were the consequences? You could see farther, and you could see smaller.

Industrial period was basically the invention of photography. So in addition to the eye, the transduction element and the storage and display element was now technological. What are the consequences? We could expand into invisible spectrum.

Now, one has to remember, without photographic film, x-rays would never have been invented because [INAUDIBLE] figured it out that there was something going on because he had this film that was [INAUDIBLE], and it still-- something happened. It exposed. So invisible spectrum, then second thing is time sequence recording allowing the analysis of very fast or very slow events. Time lapse photography and other things, so detailed study of motion that went well beyond the human time phase.

However, everything was still non-real time. You still required chemical processing, and processing and exploitation was still by humans. So as we move forward to the modern era, 20th Century, it really is a revolution in imaging sensors, where the processing and exploitation is still primarily by humans, but that slowly is moving into a completely automated image exploitation system. And I just thought this is an interesting example.

I don't think the Pee Wee soccer league still has a goal line camera or something to decide whether somebody was offside or whatever, but it's really a matter of time. And why is it a dramatic break from the past? Real time acquisition, no chemical processing, real time processing, and [INAUDIBLE] scalable manufacturing, at least as far as sensors are concerned. And now, with the wafer level camera and new designs for front end optical elements, that scalable manufacturing is also moving towards optics.

And let me see, this-- I don't know. Did you show this [INAUDIBLE] in the class?

RAMESH RASKAR: No, I haven't.

RAVI ATHALE: As I was working on some of this presentation, from this very interesting article from Nathan Myhrvold-- people know about Nathan Myhrvold, and his-- I think he was employee number 15 or something at Microsoft. And from what I understand, his primary contribution to the thing at that time, to have a standalone company that is solely for the purpose of developing systems software and making money on that.

So his contribution was the business model for Microsoft, and he's currently either the most famous or most reviled person in Silicon Valley for having started a company, Intellectual Ventures. And again, he's trying to do a business model, that a company can exist solely for the purpose of inventing things, never commercializing, never prioritizing, but essentially filing the patents and sitting on them, and either licensing it or suing people who they think violated the patent. It's a very interesting business model. So obviously, he knows something about these things.

He made this comment about, cameras will also change form. They are film cameras without the film, basically like the early automobiles were a horseless carriage. So his point is that camera stores of the future will surprise us just as much.

And I was making this comment, somebody said, oh what the hell is he talking about? The automobiles are still the same as in 1910. 100 years later, nothing has changed. It still is internal combustion engine and transmission and wheels. Well, yes and no.

So now, we thought that we'll take this analogy a little bit forward and say, so horse drawn carriage, horseless carriage, to the family station wagon. Up to here, you can say really, it's more sophisticated, but nothing has changed. But then you say, what else has happened?

And automotives, tractors, [INAUDIBLE], a tank, to that [INAUDIBLE] that's allowed to split the lid. And this, of course, you recognize that as Stanley, autonomous vehicle.

So if we say that film cameras-- filmless cameras-- I really love this picture because both of them are cameras. Identical. This-- these are all film backplane. That's a CCD backplane.

So where is it going in the future? What are the future directions? And at least our projection is where it's going in the future is specialization and [INAUDIBLE], that the same concept, of course, there is some energy source, and there is some mechanism to convert that energy into mechanical motion. So in that sense nothing has changed.

But if you look at this and this and this and this, each one is designed for a different purpose. Each one is specialized for that particular purpose. So similarly, cameras-- right now, a camera is a camera that takes picture, whether it's the Hubble, or whether it is your cell phone camera or anything, or the pill camera.

The structure and function, so far, hasn't changed at all. And that is where we feel a dramatic break coming in the future because of the flexibility of the technology, because of very specialized applications, very specialized constraints for things. So why if shouldn't there be-- you can say, just like there are ASICs, Application Specific Integrated Circuits, why shouldn't there be Applications Specific Imaging Systems, ASIS?

So [INAUDIBLE] autonomy that an imaging sensor that decides, on its own, without any manual intervention, where to focus on, how to interrogate the scene? And this is sort of reworking the biological inspiration. The cameras are really replacing the human eye with trying to form a similar kind of representation, whether it should go to the biological world, it's a vast array of different types of imaging sensors. It's probably not even proper to call them imaging sensors. They are more like spatial sensors.

The most primitive form, an earthworm with a light sensitive skin that simply is able to distinguish there is more light on this side versus that side and can steer itself accordingly. And then a variety of techniques for the insects and other creatures, and these, their spectral response, the processing, the functionality just exquisitely evolved for the specific evolutionary needs of the animal for their survival.

And I don't know if I really-- I think I would like to sort of-- the optics is now getting there. [INAUDIBLE] plastic lenses, diamond [INAUDIBLE], microfabrication, wafer scale assembly. So the grind and polish technique for making optical elements really is, now, relegated to very high quality specialized.

And processing embedded in the cameras, that's the first step right now-- red eye removal, face detection, smile detection. And this is, of course, illumination. Right now, we are still using this dumb flash that this goes. So spatial temporal coding of illumination in order to enhance your ability to extract information from the scene. Different spectral regimes for exploiting that information.

And this is some picture gallery of new optics. That's the Kodak microlens array, folded optics, diamond turn optics, and free form multi scale conformal optics.

RAMESH RASKAR: What do you use it for, the last one?

RAVI ATHALE: I'm sorry?

RAMESH RASKAR: What is the use of the last one?

RAVI ATHALE: I don't if this is any use.

[STUDENTS LAUGHING]

STUDENT: It's cool.

STUDENT: It is cool.

RAVI ATHALE: Yeah, this is just a technology that's there. You saw, in Charlotte, they had this machine there. They can do this.

RAMESH RASKAR: They can etch away optics using it.

RAVI ATHALE: I think it's a six degrees of freedom machine for turning, and then you can do that on a conformant surface. And these, I think--

RAMESH RASKAR: Just going back to your previous comment, so everything is moving in a direction where the things are more programmable, more specialized, but in the basic laws of physics, are not going to change. You're still going to convert photons and electrons and so on. And so are there some-- if you want to build an aircraft, you're going to use Bernoulli principle. If you're going to build a vehicle, it's Newton's third law. It's just going to use those laws of physics.

RAVI ATHALE: Yeah.

RAMESH RASKAR: Is there something fundamental about imaging that we should be challenging? Oh, should we continue it as the same laws of physics?

RAVI ATHALE: And what laws of physics? I think it may not be like challenging laws of physics, but what are the laws of physics that we can bend, or that are various qualifiers? So one of the things here, resolution is limited by the wavelength of light. Yes, as long as you are in the far field regime, as long as you are in the linear regime, you highlight one of these, and you can do whatever you want.

If you are proximity near-field scanning optical microscope, you can get as small as you want. But if you have nonlinear, these fluorescence microscopes, you can get 50 nanometer resolution with visible light. So that is some ways in which you can really carefully look at what we consider to be fundamental limit imposed by physics and say, what is the fine print, and can we violate that? So that would be very interesting to look at.

RAMESH RASKAR: Yeah, but I mean, can we start using our own bodies as optics? Or can we start using biological principles to solve the five w and one h problems? I mean, in the film world, we actually use the chemistry to solve a lot of the problems. Now, somehow we have forgotten chemistry, and we are more back to the physics now.

RAVI ATHALE: Yeah, I think-- I don't know. One of the things I wondered, can we have a three dimensional detector, a volume detector? And if we can store it, what will it record? How will we read it out? How will we process it?

Some people have talked about directly recording the coherence function instead of just measuring the intensity. And you can imagine that now-- of course, you can wave the wand and say nano, and everything goes away or everything is different. But to some extent, that may be true, that if you are able to control the material at deep, deep, subwavelength level, you can do some pretty ridiculous things.

So that's the direction that we haven't really explored. And another interesting thing is that, if you have the ability to manipulate matter and control it at deep subwavelength level, then it's really incumbent on you to abandon your other cherished notions about, oh, a spherical lens forming a well focused image on a focal point. Why are you sticking to that part of it?

So if you really fully want to exploit the ability to manipulate the electromagnetic wavefront in very novel ways using very novel materials, you should also start thinking about what are we going to measure, and how are we going to measure it? So I don't know if I answered your question.

RAMESH RASKAR: Yeah, I mean, it's an open question.

[INTERPOSING VOICES]

RAMESH RASKAR: Yeah, I don't think there's a clear direction. But I mean, the chart that you showed earlier of different stages where biological-- I mean, not biological, but human involved, and then we got more and more technological. Now, everything that was blue has become pink.

RAVI ATHALE: Yeah.

RAMESH RASKAR: So what's next?

RAVI ATHALE: I think maybe just what kind of technologies? I mean, you can think of some of the things like, can we think of self-assembled imaging sensors that are not lithographically driven or that are not mechanically assembled? Yeah. I don't know what else.

RAMESH RASKAR: It's like the discussion on similarity. It's almost easier to say it's coming tomorrow, but when you go back, it seems like a lot of stuff has to happen before we reach that point of--

[INTERPOSING VOICES]

RAVI ATHALE: And many of the turning points in technology are turning points only in retrospect.

RAMESH RASKAR: Yes.

RAVI ATHALE: So you say, ha, that was the day world changed. You didn't realize that time, but-- I mean, the 40 year anniversary of the internet, and there was a story about what was the first message sent?

First message was "log in." And after L-O-G, the computers crashed, and they had to reboot. And so they asked the person from UCLA, so what did you do after you send a message? Oh, I went, had a burger, and went to sleep because they didn't know that revolutionized or something. It's only in retrospect.

And these are some interesting examples just to say application specific imaging, and this is one example from a surgeon in Naval Medical Center. They're using the three CCD camera on a laparoscopic tower, and basically, his point is that, when you are doing surgery, it's really important to know which is the artery and which is the vein.

You treat it very differently. And you start off, say-- I mean, hey, color coding wires. Unfortunately, in the body, it's not that straightforward.

So taking these three colors and then doing the processing, and using many of the things that you saw here, that you can really-- a very distinct spectrum for the hemoglobin and oxygenated hemoglobin. And so by doing the processing, you create that map, and you project it back. You show it. Veins are colored blue, and the arteries are colored red.

Now, here in this particular case, the surgeon looks at the monitor and says, ah, this is the one that I should be careful about, or whatever. But then some of the things-- I don't know. How many of you have seen this thing called Vein Viewer? Have you seen the product?

I don't if there is a wireless connection is good enough. We'll see. It might be working. Yeah.

[INTERPOSING VOICES]

RAVI ATHALE: You have seen that? And if you look at the technology, it is just absolutely stupid technically. It's 780 nanometer light illumination that you do that, and that penetrates the skin and is absorbed by your blood.

And so you can see the veins deep inside, and the beauty about this is a camera is up there, and so is a DLP projector. And the processor basically scales and aligns the images so that it is projected back exactly aligned like that. But the use is phenomenal.

RAMESH RASKAR: Yeah, it's one of the best forms of augmented reality.

RAVI ATHALE: Exactly.

RAMESH RASKAR: So I always show it in my augmented reality presentations.

RAVI ATHALE: Yeah, and I think the rest of the thing may be-- I was talking to Ramesh. This is Doug Hart's company, Brontes Technology for the 3D. I think you saw--

RAMESH RASKAR: We saw it--

RAVI ATHALE: You saw that, and [INAUDIBLE] chair side oral scanners. I think there was a video. Did you see that video of the doctor manipulating in the--

RAMESH RASKAR: Did it show the video? I don't remember. [INAUDIBLE]? I forget.

RAVI ATHALE: I don't know. It's not that important. You know what it is--

RAMESH RASKAR: Yeah, it's amazing how simple it is.

RAVI ATHALE: Yeah, and I think, this is one of the things that maybe-- and the refocus imaging, of course. You don't need to, right now, know anything more about it. But in some ways, when you talk about application specific cameras, the key is understanding the nature of the problem and finding the simplest solution to that specific problem.

And one of the examples, you saw that Vein Viewer, all of you know the pulse oximeter that is clipped to your finger. It's relatively new. I think maybe 20, 25 years old technology.

Again, if you look at the technology, it's absolutely dirt simple technology. Two different ladies looking at the differentiable absorption through your finger to measure the oxygenation level of the blood. And before, they had to draw the blood and send it for analysis, and by the time it came back, maybe bad things happened. But this one is now, you saw in all the TV shows anywhere, the first thing they do is clip this on your finger. And I don't know how much it costs--

RAMESH RASKAR: It still costs $1,000. I don't know why.

RAVI ATHALE: Because somebody's making a lot of money. That's why. I think--

STUDENT: They have a patent.

RAVI ATHALE: Yeah. But that's some of the research projects that I was involved in monitoring. To talk about, can you do a spacial map of oxygenation levels using these multi spectral cameras and then processing?

And the doctors got really excited for applications like burn assessment, whether it's a first or second or third degree burn. The treatment differs dramatically, and instead of relying on the doctor's visual assessment of what degree burn it is, if you can take a camera that can do that blood oxygenation map, or if you can map the retina and a lot of the diabetic retinopathy and other diseases, there are precursors are in, what is the oxygenation level of the blood [INAUDIBLE].

So these kind of things, just like the distinction between arteries and veins or the Vein Viewer and all that-- you don't need to invent new nanotechnologies or something. You need to understand in depth what the problem is and what the human factors is.

Again, this thing, Vein Viewer-- the cool thing is not just that IR LED, but you can imagine everything else the same except that image being shown on TV, and it will nowhere be as dramatic if the doctor has to manipulate the needle here while looking at the monitor. It's a human factor, so right there. So that that's really where-- so this is the last slide.

So just a little bit science fantasy, not just fiction. A personal imaging assistant, something that just like you carry your pen every day, or your wallet or credit card or your cell phone. The personal imaging assistant-- what all would it do?

Health care. Checking for sunburns, or if you get scraped, hey, is it getting infected, this wound? You have an attachment?

You check the ear infection of your children or whatever. Look at your tongue. Are you getting upset stomach?

Wardrobe matching, of course, color and styles, especially. What kind of makeup will go with this, and other things. Hygiene, cleanliness of surroundings, presence of bacteria, water/food safety, quality of what-- The last one, it's really getting a little bit science fictiony, but maybe not given that sixth sense thing.

So you're wearing these glasses, or this personal [INAUDIBLE] assistant with a headphone, and somebody walks-- Hey, Ramesh, how are you? Somebody, this person, [INAUDIBLE] It's like the politicians who have these assistants at their elbow who whisper in their ears who is the person walking in, and discerning move, that's again very science fictiony.

Can the image tell you that? This guy is very skeptical. He's not buying anything [INAUDIBLE] of course, taking pictures, and how it's basically exploit the electromagnetic domain to the hilt.

Combine the processing right there and have an adaptive-- one analogy that people make. Right now, it's a sensor with a total one directional flow of information from the sensor to the processor to it. How about going back?

I heard somewhere about human visual pathways from the retina to the lateral geniculate nucleus to V1 and all the inferior temporal cortex and all that. Everybody analyzes that feedforward and what kind of features are extracted. And I heard that from V1 to [INAUDIBLE], there is a huge amount of feedback connection. What's the role of that? I don't think the neuroscientists know yet.

But that kind of a thing-- an imaging sensor that analyzes the scene, says now, next, I should look in this direction, in this spectral domain, this place of something. And in a few of these adaptive steps, can learn a hell of a lot about what is out there.

So last thing, unobtrusive or most covert form factor, and it's literally part of getting dressed. Just like carry your wallet, your cell phone, carry your imaging assistant that can do all of these things for you.

RAMESH RASKAR: But what form factor? Is it in the clothing or is it--

RAVI ATHALE: That's interesting in your eyeglasses, eyewear kind of a product. Or I was, this morning at [INAUDIBLE], I was looking at some of these glossy magazines for Army, and I noticed that all the soldiers in Iraq and Afghanistan, their helmet had something there. And I asked what is this? They said, of course, it's a video camera, so it's part of a standard military equipment.

So I don't know how unobtrusive you can make it. Is it in the clothing? Is it something that you clip on your shirt, or is it here? Hey, you are in the media labs. You figure it out.

So well, that's it. Thank you.

RAMESH RASKAR: Any questions for Ravi? And we can make your slides available?

RAVI ATHALE: Yeah.

RAMESH RASKAR: OK.

STUDENT: Can I ask a question?

RAMESH RASKAR: Yes.

STUDENT: So there is this problem in biometrics that you want to capture-- where you want to recognize a person at a distance, and maybe they are pushing programs of iris at a distance or face recognition at a distance in [INAUDIBLE] things like that. And there are two problems in this. One is atmosphere between the subject and you, and the other is subject is-- he does not want you to recognize him. He's uncooperative.

What would be your ideas in terms of how our image sensors should go to capture that problem? Because if we have a really good image, then we can run our recognition algorithms, and then we can focus more on recognition aspect rather than dealing with issues like atmospheric issues and stuff like that.

RAVI ATHALE: And that's a very broad question. It also touches upon some very sensitive topics, as you can imagine. All I can say is that that program announcement is public. Right?

RAVI ATHALE: That is--

STUDENT: [INAUDIBLE] not the only one that's interested. [INAUDIBLE]

RAVI ATHALE: There are all kinds of agencies interested--

[INTERPOSING VOICES]

RAVI ATHALE: Yeah, there is a program enhancement called Best Biometric Exploitation sponsored by--

STUDENT: Biometric exploitation?

RAVI ATHALE: Science and technology. Out of this agency called IARPA, Intelligence Advanced Research Projects Agency. It's a multidimensional problem, and there are all kinds of ideas that are proposed. Hopefully, within few months, the contracts will be awarded. We'll find out what.

But I think somewhat going beyond that, I think really in imaging senses-- and this is a debate that we are constantly having. Is it necessary to form an image? And if you don't form an image, if you just map directly into features, number one, can you do that? Number two, should you do that? Is it advantageous in some form or fashion?

It applies to biometrics as well. Right now, for iris recognition, there is the dogman algorithm. So that is geared upon you sampling the iris at a certain resolution in a certain way. But if you tie the front end acquisition to the exploitation, could you get into a more robust, simpler system? That's an interesting question, but it's a little difficult for sponsors to launch in that direction because too much risk, and if something changes on one side, the whole thing may collapse. But that's an interesting point.

STUDENT: Yeah, I think the point I'd make is that, as long as you continue to rely on collecting a high quality image to do this, I think doing it at a distance is going to pose a challenge. And the dogman algorithm is a perfect example.

You start out with an image that's several hundred kilobytes, and you end up with a template that's a couple 100 bytes. So obviously, you don't need all that data that you collected in that high resolution image to do iris recognition, so why do you need to start with that image in the first place?

And if you could develop a compressed representation, if you could sense that compressed representation directly, would it lead to a simpler system? Would it lead to a simpler and more robust system? That last question is very tricky to answer, and the three of us said [INAUDIBLE] when he was with us four of us [INAUDIBLE] gone over this over and over, and we still haven't come to a conclusion.

STUDENT: Thanks.

RAVI ATHALE: Sure.

RAMESH RASKAR: Good. So hopefully, as you already saw, a lot of the project plans are also about not-- not about standard cameras and then exploiting specialization and autonomy and trying to change a lot of the rules here.

RAVI ATHALE: And as a matter of fact, many of the projects we looked at each other and said, hm, should be talking to these people?

STUDENT: I'm going to come back and visit.

RAVI ATHALE: Yeah, exactly.

RAMESH RASKAR: Yeah, welcome-- you're welcome to sign up as a mentor for the class. So we have several mentors for the class, and you're welcome to sign up for that. So excellent, so next week we have the midterm exam.

It's open book, open laptop, open internet, open everything, so don't study for it. And it will be mostly about drawing diagrams and explaining things and problems that will make you think. And eventually, after that, we'll be studying animal eyes, which is [INAUDIBLE] 13th of November.