Good afternoon.
Today is the last imaging modality optical imaging.
And we do not have optical imaging chapter in the green text book.
So this lecture is standalone.
So you better view this lecture as a story.
So try to follow the story and make things interesting.
So you understand what's going on with optical imaging.
And then we talk about machine learning and final examination.
So we pretty much done.
So today is outline mainly four parts.
First part, I think optical macroscopic imaging is a classic.
And first time this magic device enables you to see individual styles.
Even sell the vision and will show you picture.
So this is very cool.
So I will review with optical imaging, macroscopic imaging, typical things, small tissue culture.
And you can see small features.
So you will first need to know little bit.
What's the visible light? The light is a portion of electromagnetic wave.
And also light will interact with biological tissue.
So all the features and the swan biological features.
So you know little bit.
So the tissue optics and the physical principles.
Once you learn the first part, you are prepared to move to the second part.
Optical coherence, tomography.
Again, I will tell you little bit principle, very cool principle, interference.
So I will give you applications, OCT.
So both microscopic imaging and OCT optical coherence tomography, these two are real stabilizations.
You know biology rely on optical microscope.
In clinical, eye clinic, particularly, you use OCT.
So these are real things.
There are many imaging modalities.
But what are important ones? Important means in hospital clinic.
You really use it.
There are some fancy things.
There are some fancy things in the paper, even in science and the nature of article.
But you go to hospital clinic like quantum doctors.
People wrote a lot of science, nature, got a lot of money.
And you see doctors, they never use quantum doctors into you.
Right? There is no real societal impact, at least, at the moment.
So I focus on these two parts.
I will give you some little bit more mathematical details, particularly understanding the inside ideas, the first two parts.
And the last two parts is more like a research topic.
In small animal imaging, they feel the optical imaging, like fluorescence, bioluminescence, those biomarker, cellular molecular imaging, these are how to research topic, but not used for patient.
But we just mentioned little bit.
So the last two parts are kind of research topic, this is for you to know.
And also homework, last slide always.
And I suggest one homework question.
Because we don't have text book.
I try to explain, I think slides I reorganize, previously we used two lectures, four hours covering optical scenes, and the crazy reason.
So last night I tried to combine these scenes into single lecture, I made a research lesson, so I think what I selected, my judgment, usually much better than student judgment.
So I think this is something really important, I selected, I make a story easy, so if you just follow me, treat us, you are smiling, so you will understand.
And you can, this is right key point, so I'm key scenes, what's OCT, and what's D O I S D O T B L T, what's principle, so those things, you can just write summary, outline key points, for your examination three.

This is the one thing.
And the optional question, I make two, why is that? You can just transcribe what I said, make this, I'm writing book chapters, book, multiple chapters, optical imaging chapters, I'm pretty happy with the current outline.
So what I said, certainly you wouldn't put exactly what I said.
This is the logical flow, you just write it up, that will be draft of chapter.
This optional, you are unalaising your want to do, you're not required to do.
If you do not send your want to T A, send to me, I will grade, see if you have a key point.
And as I said, I think optical imaging is a very interesting story, so let me start the story.
And at the beginning, there is light, okay, so you have the EIM wave, wide spectrum, we already involved the gamma ray for nuclear imaging, X-ray for CT, and you have the visible light, this is radio frequency range, and we use the four I-MI imaging, and this is the RIF part, but in daily life we use RIF to cook food, so on.
But anyway, now we're talking about this visible light.
The visible light range is very narrow in the wide EIM spectrum.
And to be specific, so I really made the bottom part very clear, so what do you mean visible light, so visible light, if you look closely, you may say, okay, from 400 nanometer wave lines, all the way up to about 1000 nanometer wave lines, so in this wave lines, we visually perceive as say, right, yellow, green, and blue, and just keep going.
You're very familiar with this, this is prism, you will see this.
And if the wave lines are little bit longer, you will see, wave lines are 2000 nanometer, you cannot see, but the exact visible range depends on species, and therefore some animals they can see frogs, some wild frog, some report says, frog could see eggs rew, you say, eggs rew, the frog will react, as recorded by E-R-E-E-E-Lectro-Retino-Gram, ERG, so there are some science articles talking about that.
But even for human beings, among ourselves, the different ones may feel little differently, and some might even couldn't see, could not perceive color, only grease, called color blind date, maybe few percentage, I need about 1 percentage.
But anyway, so this is basic knowledge, crystal clear, why the wave lines medical imaging use, use different portion for different modality.
Now we're talking about the the portion we can directly see, that's light.
So the optical imaging very much utilizes the wave lines in this range, particularly near right, or near infrared, far infrared, the right goes far.
So that's good for penetration depth.
So we have this physical knowledge.
And the light, like X-R-E light, generated, X-R-E-V-U interact with tissue in parallel, visible light, will interact with biological tissue as well.
As graphically shown here, I think it's clear, you have an incident light, could it be reflected a little bit, and some transmitted into the tissue, subject to scattering, the scattering goes randomly, some scattered signal may go back, so red-eye-meted and others will go through.
So why would the thickness of the tissue, this is penetrated? These are pretty much typical mechanisms.
So you can say, transmissions, scattering, reflection, so you can raise these things.
So you send the beam into a piece of tissue, so some just go along the same direction, transmitted.
And the attenuation could be due to two things, very much like X-R-E.
Obsolvesin and some light inside the tissue is observed and becomes a heat.
And some just remove from the primary properties and direction, due to scattering.
So very much the same thing.
So you understand this.
The scattering due to all these different structures can be classified further.
So this depends on structural details and scale level.
So scattering mechanism may be further characterized.
And in certain sides and you have so-called really scattering.
And in some middle rings you have so-called my scattering.

Those details, the formula, the physical mechanism, I'm not going to explain to you.
Just say light, visible light, directly interact with cellular molecular features.
Like all these relevant scales, they have optical interaction.
And based on optical signal, you can infer the styles in working.
So this is very biologically friendly.
So this is something more informative, relatively to gamma-ray and x-ray.
So more biologically relevant, biological resolution with optical imaging is the best.
So far.
So the cellular scales are very small.
The style is small.
But if you look into detail, there are a lot of structures.
Each cell like a small unit versus many things.
Usually the sides of the shell is basically unit.
You know, most of the famous journal, science, nature, the certified style is building block of life.
And we mention machine intelligence, particularly next lecture.
So we use neuron-neuralized function to do processing, logical processing, computational purpose.
So the diameter is from actually here.
From actually could be from one to 50 microns.
Just different style, many types of shell.
And you look into shell, you have a nuclear, you have a membrane, many channels, a lot of things.
So scattering happens in this different way.
We will have different optical properties.
And very complicated.
But just to say, scattering is interesting.
So far, this is say some typical physical visual optics interaction.
Okay.
Transmission, absorption, tiny-way-scent, scattering, just and the opposite-scent scattering put together, when we call it a tiny-way-scent, very much like x-3 terminology.
And in addition to these x-3 pretty much parallel, similar stuff.
And we have some new mechanism called for fluorescence.
For x-3, we also have x-3 fluorescence.
And you send x-3 into certain material.
And you generate a second x-3 called x-3 fluorescence.
And you have optical domain.
And you can have some protein targeted with fluorescence protein.
So together, you have certain biological things.
You can take with this fluorescence problem.
So if these two guys link together, you think one part is your biological features or biomarkers.
The other part, you have this problem.
It's green fluorescence protein.
And the targeted together.
And when they put together, and you can try to sense where are your biomarkers by detecting the optical signal.
So this could be somewhere.
Then you send the blue lasers.
Then by fluorescence mechanism, the blue laser will generate green light out of the G-F-P green fluorescence.
So when you use the blue light into a reason, you see green light come out water you can infer.
And you know, there are a lot of lipids, because by definition, they are by design, they are together.
So this can be bio-design.
You can use G-F-P-O-R-Z fluorescence proteins, target different biomarkers.
And you have biological diversity.
Many different biomolecules.
You can use bio-engineering technology to put green fluorescence, pink

fluorescence, red fluorescence, into different reasons, or into different molecules.
When they move around, and you see green light come out, you know, biomarker green is there.
When you see red fluorescence light come out, and you know, biomarker red will be in the reason of interest.
So, fluorescence is something very important.
This work got a Nobel Prize, and I think then by several investigators in Japan and in California, I couldn't remember third one.
So basically, biological things can be observed, can be observed in life.
So you just send light, you need to stimulate fluorescence probe, and then you get some longer wavelengths out, both invisible light range.
So you can do molecular or cellular imaging.
So very easy to see.
This is a fluorescence light.
And the bio-luminousness, what's the bio-luminousness? And in the summer night, you see these bugs.
And also, in summer red world, or also you can see in the dark night, you can see bio-luminousness light, some creature, just the eye-made luminous light, oftentimes green, and pink, or all the soil work.
So bio-luminousness light, is pretty much like fluorescence light.
They all eye-mated from some light, eye-mating proteins, but the difference lies in the way they eye-mated light.
For fluorescence light, you need signs of light to stimulate.
For bio-luminousness, you do not do anything, like these small insects, you didn't use laser to suit them.
You just fly around, you see the light bulb flying around, so these are called bio-luminousness.
It's just the style of eye-mating phenomena.
So all biological things, so they can be, the light eye-mating proteins can be isolated.
Then, combine the waste target protein, then they can just label cancer-style gene-expressant signal, signal in pathway.
So, thankful optical imaging, the biology can be observed in vivo, so this is very important.
So, this is some basic sense.
So, this is light eye-mating, like fluorescence interaction.
The light tissue interaction, you sign the laser light in, that fluorescence light comes out.
This is also important interaction with the rock and the mechanism.
Okay, then we talk about how you do imaging.
The simple things, you know the new lines, optical lines, you have basically converging lines, you have diverging lines, so you know this.
I think in high school, you learned this, right? High school? No? Physics 2, you learned.
So, this is the, I've learned the things like this.
It's optional stuff, also, students require all high school students, so the no concept shown here.
So, it required, right? Optional.
Okay, anyway.
So, basically, you see, optional, so assume some of you do not know.
You send a parallel beam, it will focus on this point.
Here, you send a parallel beam, it will de-wards, and it will trace back, and you will feel, as if you have a point, it's also sending here.
How you use the new lines to form a image, you will look at this, you have a real object, so the rule is that, you send a parallel beam, it will be refracted towards a point here.
Okay, and you send, send another parallel here, it will be, send here, just as shown like this.
How you make this happen, the trick is about this curvature.
You can make the curvature the way you want.
Just make sure all the parallel beam will be focused to the point.
So, this curvature, and under certain proximation, it's spherical surface.
But anyway, this can be made.

This is, you waste this design, go parallel beam, or focus on the single point.
So, that can be done.
So, when you have things like this, we have a diagonal rule for retrieving.
That is, when you have the line, going through this is called optical center.
This is called the principle of optical axis.
So, if you send the going through center, the direction will not be changed.
This is one of the rules for retrieving.
Next slide, we will summarize that.
So, likewise, you know the optical rig.
If you go a certain way, come to this point, and the physical principle.
And you send the rebike, it will go back to the original part.
This is a reversible thing.
So, by the reversible principle, and you can imagine, you send the rebike, you send the rebike, it will go back to this point.
It's just like you send the rebike, it will go back to this virtual top.
So, all these things can be understood.
If you're waiting to spend some time, you can understand.
For example, why, why I learned this? Why you think the regal through this center will not change the orientation? So, the idea is that, you go this surface, and this surface, you have symmetric.
So, one place, you just have one reflex, and an angle introduced here.
Here, you get back.
So, you know, this incoming rig and existing rig, must be in parallel, because these two places are symmetric.
And why it goes through the center? Because this is under thin lines.
The line is thin lines, thin lines, something.
So, this second is very thin.
So, you have the rules.
As we summarize here, rule one, go center, the rig will not be altered directly.
If you make a parallel beam as input, an output will be focused on this part.
These two rules are very simple.
Second rule is by design.
First rule can be understood this way.
So, these rules you understand.
So, this real image will be converted into virtual image here.
And also, real image in the case of diverging lines will be formed just on the same side, and just reduced.
So, all these images for Mason precise can be understood.
And if you are waiting, certainly, W will be a whole other lecture about the formula, lines formula, how you compute.
But I think those are details.
And what I gave you a few points, is the way you understand how you form the images.
So, that's quite straightforward.
And the optical lines like draw is for mind.
I really enjoy seeing all these lines.
And the supervisors, one time, just polished lines, and they can make one.
So, a lot of interesting things you can enjoy.
Which all these optical things, the principle are simple as I told you.
And you can make zooming lines shown here.
And you really can see here.
So, this is very cool.
Basically, this make the blue and yellow green, you can really green, you can magnify.
Magnify the small things, you start seeing shells, you keep magnifying multi-levels.
So, the magnifying power will be larger, larger.
So, that you can see small cellular structures like this.
So, this is the basic idea.
And the very cool idea I want to mention, confocal optical, optical micro-scope, is very cool idea.
Let me just tell you the sensual idea.
You see here, you have input ledger.
The input ledger is the sign, reflect it by the mirror, coming down, zoom in,

focusing on a spot, the focal spot.
Okay, focal spot is this blue location.
This blue plane is focal plane.
And certainly, there are some other lines.
And also reflect it, not in focus, say below the focal plane.
And they notice by the dotted line.
The way you just have the light reflect it by, so this mirror is just semi-transparent.
So, going back, the focal plane, just the refocus at this point, and you have a screen, just half the point open.
So, only the light at, at the focus location, will be transmitted light, focus the light, will go back, be detected.
See any outer plane, and focus the light, say the right light, will be blocked.
So, the input is point-solid, so resolution is very high, single point.
This point, through the optical pass, becomes a single point here.
And certainly, there are some other lines, and will be blocked.
So, you have a focus, here, you have a focus, here, called confocal.
So, the resolution is very high, is a smart design.
But to guide image, you need to do skyning.
Each time, you can only take one pixel, like one plane.
You can just move in, use the laser skyning, keep doing the laser skyning.
And you can make the volumetric image.
So, this is a very important tool.
So, optical micro-scopic imaging, optical micro-scope.
So, you can just simply understand, as you have a bunch of magnetic flying glass, making it bigger.
So, this is a milestone.
And the second milestone, I would like to mention to you, is confocal.
This is a mega-resolution, very high.
You can make the flying glass, and the big structure, all the light, really form the background.
You couldn't see very clearly.
And if you interested, you click, you see cell division.
The image is formed, using the confocal principle.
The confocal micro-scopic work, was believed, while the PIC student, it's so important to click, guys know, very price, but didn't.
But this is still very, very smart design.
And another thing, I want to mention to you, optical fiber, so you have light comes in, and this wall made of high refractive index material.
So, the light will subject to internal reflection.
Internal reflection is lost.
So energy just keeps the same, but you can, just the sign, the deliver, the light, or the signal, without any loss, and the long, a linear pass.
So this is a course, you think you have this optical fiber inside, and you can see, if I buy, heart wall, the fiber sign, I think it means, transmission, this is received, your sign light, come back, the confocal microscope could be minimized, so you can do confocal inside living, animal, or human, to see structures very clearly.
So, you have the idea, optical biopsy, so you do real biopsy, use mechanical things, you will be able to see, you have the idea, you don't need, you are looking for a way, you get the piece of tissue out, you do analysis, you see, okay, this is a result.
After this week, you go to the result, it is optical biopsy.
You just put the scene optical fiber, very flexible, to sign the light, get signal, back, and the very important and the next that we will mention OCT.
So now we learned the outer sound.
So just learned the x plane to confocal.
So confocal microstecopyc imaging.
The resolution is pretty good between one microply, but the penetration depth, the optical light cannot penetrate very deeply.
This is you see my hands, so my pen, my iPhone, on.
So you cannot see my light in the foreground because it's not optically transparent.
It cannot penetrate very well.

So this is the penetration depth is not very good.
But the outer sound penetrated older of 30 meters, 10-30 meters, that's not a problem.
And the OCT is between outer sound and the confocal microstecopyc.
And these three things, outer sound optical, these are clinically, really clinically or biological, fundamental research.
These are really useful.
We always establish no question.
That's why, next, the green thing I'm going to talk about, optical coherence, tomography, principal, and application.
These two things, if you follow max-dory, very useful knowledge.
And the last two parts, not so much useful at this stage.
So now let's focus on optical coherence tomography.
So what's the difference between first part, second part, I say on the diagram, their performance are different.
But physically speaking, the confocal microstescopyc, or general microstescopyc, even data in the buzzer show, these are the multiple magnifying glass, for the tecizer.
But the confocal, you have the two focus bars, you just reject, unfocused lies.
So that's the twist there.
So that's very good.
But for the first part, you pretty much, I say, retrieving, retrieving or treating photons as a particle, so moving around.
So the first part is a particle view.
The second part, coherence, you really treat light, visible light, laser light, as a wave.
So once we have wave, then we can make some good story, particularly interference.
So we want to do some sensing, some measurement, we want to have very high resolution, precision measurement, how we do that.
So go back to, this is, trigonometry stuff.
Okay.
Suppose you have 1 wave, a cosine omega t, then you have another wave.
So suppose you have the single wave, you go 1 wave, the other parts go the another wave, the rest same direction, they are recombined.
But because the optical parts are different, so there will be a phase different.
This phase difference, when you recombine two optical parts, the signal density, as you measure, there will be a difference.
So mathematical principle, try to follow me.
So you can appreciate the smartness behind the OCT.
So this is a, one wave, you got a reference wave.
This is cosine wave.
This is a wave, a cosine omega t, and a sine wave, cosine sine of sine of sine of the form, because E, I'm Maxwell equation, you saw, wave wave is in this form, it's a fundamental solution.
So you have this wave, a wave form, very reasonable.
Because you have a second optical part, recombined, and the two parts, and not identical, so you have a small phase angle.
So you either, these two wave together, whatever will happen.
So mathematically, you have first, the signal from, pass one, signal from, pass two, the only difference is, it's a phase angle.
So you think, this is cosine function, this is cosine function, this amplitude is same, and this angle, is a reference.
The other angle, is outside by five.
So the first angle, A, the second B, and we have this identity.
So the sum of two cosine terms, can be x-price, or two times, two factors, cosine and factors, these angles are, and the, our, our risk-make mean, and these, difference divided by two, just, just, identity, so you have this.
Then we apply this to our particular case.
So the, our reason, our reason, you got this one, okay? Then here, the, the, the difference, you got, you got, so the overall y, you just, copy this, okay? into this one, and this one.
So this becomes, A plus B, A minus B divided by two.
So you just do simple, minus, you see the result, it seems like this, okay? And

A minus B, just, remove this fundamental oscillation, because this A, this B, you do sub-traction, what's life, is only the face angle.
So face angle, is today here, as a constant, no longer oscillating.
The geometrical, not geometrical, a, a risk-make mean, and still have this, omega t, this is oscillation, you got this one.
So this is oscillation.
And whenever you do signal measurement, actually signal, optical signal, you cannot measure oscillation.
What you can measure is, this amplitude squared, this is the, squared is the power, that is you can measure.
You cannot measure face directly.
So see here, if you do measurement, which you signal, along optical pass one, so the intensity, is proportional to A, A is amplitude, proportional to A squared.
Now, if you recombine the signal, after interference, if you do measurement, measurement will be proportional to this squared.
So this squared will be 4A squared plus this, face factor.
So this A squared is I, 0, is just the reference intensity.
So 4 times the reference intensity.
Then you have a very important multi-placate face factor.
So small face change, the 5, small face change, the face change over the wave lines, wave lines is very small.
So over small wave lines, the face change can be from 0, degree to 90 degree, 180 degree.
So if 5 is 180 degree, then divided by 2 will be 90 degree.
90 degree cosine is 0.
So that depends on the small face change.
For 5 over 2, so this change is also listen, this is you need half wave lines.
Then you measure the intensity.
From I squared can be I, I 0, no, I 0, from 4 I 0.
So very strong signal.
This small change, all of sudden drop to 0.
So this is the wave, you can measure the accuracy, order of optical light wave lines.
The wave lines is so, I just mentioned, 400 nanometer up to 1000 nanometer.
So you can do the measurement that precisely.
So my core level thing, even better, can be done.
So this is a principle, you see, you compile reference intensity after interference.
So intensity is modulated by cosine square.
This is 5 over 2.
The 5 over 2, the 5 change over 1 cycle.
The 5 will change 100, 300, 6 degree.
So this can modulate.
And that's the reason you can do precise measurement.
And this formula is cosine squared angle.
It can be I could surprise this way.
This is the simple trigonometry identity.
So remember this one, then let me just show you interference of coherent light.
And I mentioned optical pass, optical pass, what do I mean? So suppose you have coherent light, right light is coherent.
You have multiple of light.
So right light has a wavelength lambda 1, the orange, green, purple, so on.
So this is the look at the right light.
The right light is the same.
This is a wavelength different.
But this is the first case.
So you think the light is sanded this way.
From the salt, it is cated the mirror.
The mirror passively transparent.
So transparent light goes this way.
So it's a perfect reflector.
Then goes back, hit this again.
Posing all the way will be redirected down.
So this is pass 1.

Another part say the light hits this one.
This is partially transparent.
Also partially reflective.
So the light will be reflected upward, hitting this movable mirror.
But it's also perfect reflector.
The light will be sanded down.
Sanded down, because this is semi transparent, light goes down to the same photo detector.
So these are two optical paths.
If the two optical paths are exactly the same, so this is fixed one.
This is movable one.
You can move the mirror to so that optical paths one and two are exactly the same.
Exactly the same, the two signal recombined in phase.
So signal will be enhanced.
If you just move the mirror by half wave lines, so the one that is signal comes back this way.
The other signal comes back just face flip.
The other signal recombination signal here will be 0, measure as 0.
So you just move this slightly over half wave lines to see.
So this is the wave you can measure.
So the essential idea of inter-interform metric measurement, just like that.
So we have the formula derived on the previous slice.
And using this is what we derived.
And this is equivalent to this one.
So one plus cosine.
Some things is one plus cosine.
This is a five factor.
This is really just the delta i-oh.
The optical paths lines difference times frequency.
That will be the time is too high.
That's the face angle.
So we keep talking about face modulation.
So this is the formula for right light.
And for orange, green, purple.
Because the frequency is different.
But you can treat individually.
This is a linear system.
Then you add it together.
So you can treat the whole thing as a partially coherent light source.
Then you have partially coherent.
You have different components.
You added the together on the left hand side, on the right hand side.
You have something like this.
And the result of this summation.
If single components will be modulated by this cosine term.
So you have this single single-synosoidal wave form.
But you have multiple things.
The formula will be shown here, like this one.
So this is modulated by, you see, modulated by cosine.
You have cosine components.
If single components, you have cosine components.
Second, you have cosine components.
But they are not in the same frequency.
You added the together because the frequency are not the same.
Ineasantly, then they line up.
But when you move away, they go out of phase.
So it will show us these cluster things, like this one.
So we think, if you have many, many components, like siphon components.
And this is the visually show you different color components.
You added the together.
The result will be, since like this, Gaussian profile, somehow.
So if you just take a limit.
All these summations, the small intensity components, times delta, delta V, that

give you the energy within small energy beam.
And you're taking a limit, the summations become integral.
So integral, this is light power spectrum.
And this is cosine components.
And if you recall Fourier transform, this is nothing but Fourier transformation.
And you may say, Fourier transformation, you have this as e is exponential.
But here you only have cosine.
But remember this, this is also, we say, oh cosine, that's even function.
So the Fourier transform, you only need the cosine kernel here.
If you just introduce multiple sine components, then this will be a sine sense here.
You add together, you really return to Fourier transform, transform, and this is the result.
You can measure.
So from the measurement, you can see if the mirror is moved.
So if the coherent lines and the optical pass lines, difference, they match.
You can detect.
So this is the essential idea.
And the movable mirror, you can sync the image.
You are going to like a time like you've written on.
It's just not on the same plane.
Some move forward, some move back, because it's a natural contour.
So that will give you a different signal.
So you can recall the signal, you display.
That's the image.
So this can be used for multiple things.
Medical image is one thing.
And fundamental physics, use this measuring interferometer.
And do the measurement to determine if speed of the light really associated with moving frame.
And the experiment was performed in case of accident university.
And just in all the time, based on the experiment, they didn't find any evidence that speed of light will change.
Based on reference code in the system.
And the arboride, and say, and take speed of light, as constant.
And he just published some more people, so very so relativity.
So this experiment, based on the principle, I explained.
And this experiment, see here, marked the starting point of modern physics.
So what's the division? Modern physics is classic physics.
And this is the experiment.
So this is very cool.
For OCT, it's the same idea.
So you see, you have the legular goals.
This beam is later.
You go one way reference mirror.
You go down.
And this line is used to put all the light, focus all the light into a photo detector.
And you can digitize, you put one dot here.
And the other path goes this way.
And reflect the back.
This is mirror.
Reflect the back.
Really just imagine you just keep going.
Hit the target of the focusing.
Hit the target.
Reflect the back.
The two way signals will be recombined depending on relative, 5.
You get different signals.
Point by point.
And you report, you report the structure.
So this is essential idea of OCT.
And most of the use of eye-cure, eye-acadermination.
So this is normal retina structure.

You see the second is here is a quarter of a millimeter.
So different layers.
So different layers, you have different penetrating, Dive, different interference signal.
So what I explained to you is a very simple principle.
But in reality, you need to have laser scanning.
You need to do Fourier analysis.
So you try to do 3D image very precisely.
So this is the basic principle.
Like this, we will introduce many variable, different kinds of imaging techniques.
And also you can make a optical biopsy fiber or catheter.
So it is very simple, flexible optical fiber.
Do you know OCT on the table of fiber? And into the blood vessel.
So you can see if the inside feature, if you blood is got cloud, or just some plaque is causing, or just lipid, so with OCT, you see clearly.
So this little inverse, but give you very precise clinical diagnosis.
We know the nature of plaque in the human heart.
So this is a very cool technology.
Okay, we have about, how many is the right? Then we finish the second part.
I mean, certain force parts.
Continue.
So the first part, I explained the key ideas.
I think several good ideas.
Optical imaging and microscopic confocal idea.
It's a wonderful idea.
No very price like OCT.
Pretty good.
This is comparable how you use interference imaging.
Not only OCT, interference, interferometric imaging.
The principle, no very price thing.
And the recent, you may read the news about guavelletational wave detection.
How they detect guavelletational wave.
And the wave generated small vibration.
Very, very small arbutans and thought you would never detect how you do that.
You use interferometric.
The two parts and the small difference will be magnified.
And the two arms are very long.
I think how long you remember miles, several miles long.
When the other arm, they try to put, I think two set up and they try to detect.
I know some programs are going on in Europe, United States, and even China.
They try to make interferometric imaging using satellite.
Make the arm even long.
But interferometric imaging is very helpful.
Why you have wave nature, wave one reason, very, very good reason.
You want to make precise measurement.
You need to utilize interferometric imaging.
Very cool.
And these two things, confocal optical coherence, tomography, or inter-optical, or generally interferometric imaging.
Not only optical, Ix-3 and the guavelletational wave.
You can all utilize the small slice I use, the cosine omega t plus cosine omega t plus five.
It's more or less, this simple idea like that, multiple no-ver price.
So these things are very useful.
Now, we talk about Samsung.
The difference we talk about, they fuse optical imaging and several things you do not know yet.
But you will know.
So light diffusion is a very important thing.
I say the third part, fourth part, not in practical use yet.
At least not in common use.
In research setting, you can do so.
Now, Ix-3 imaging actually goes straight away.

So, so as this purple line, straight forward, so you got signal.
The signal is lying integral along the path.
So everything I did together, the actually may be a tiny little more or less, but all can be explained by the linear dilution coefficient along the ray.
So you know any change must be due to features along this ray.
So you have the localization claim.
It's very clear.
But for optical imaging, optical lights, remember I draw and show you a small cartoon, a smile, a scatter light, a my scattering, a very strong, a very strong, and don't need to say a lot of things.
This thing you have a bright laser in dark room, you shoot laser, you see, you have this diffused light.
So all things smeared together.
Can you see things behind your finger? No? So Ix-3 imaging is to make a picture from Ix-3 data.
So here naturally look like a projected image.
You already see something.
Optical light, you shoot a parallel beam laser.
What you see is really a my-say clouds.
And then optical imaging say, this bite, this strong scattering, and I want to make an image.
Just put a very simple words.
I want to make good image behind the finger.
You just feel this nearly amazing impossible.
So it's not easy.
It's a why optical imaging is not so easy.
You can guide some information.
But still, still not as practical as Ix-3s, and other medical imaging modalities.
So scattering is a problem.
But we want to study.
Because optical interaction with biological tissue is very important in the information.
So we know it's hard.
We are here to address engineering challenge, make impossible into feasible things.
So we try to do our work.
So this is your understanding why it's difficult.
So we want to study the way.
So we do first thing.
How light propagate into the tissue? Highly strongly scattered.
That's just the verbal described thing.
But we want to ask engineers.
We want to be quantitative.
So we can decompose animal piece of tissue, hydrogenine tissue into small element.
So this is small element, usually in 3D.
So this is the tetrahedrons.
It seems to put together.
This small tetrahedron unit is uniform.
Then we just sign the light into the tissue.
See what will happen.
It will subtract to the interaction and mention the two.
So once the light is hit, it surface.
It may be reflected, maybe transmitted, if the optical properties do not match, it will subtract to reflection.
So the angle deviation will happen.
And once you inject it into the tissue, and the more certain long pass, it will subtract to scattering.
All these are probability events.
So you can just trace step by step.
You use the random generator.
This is the screw dies.
You decide if this should be reflected or coming on the go how far it will be

scattered into what direction.
You use random number generator.
Keep tracing one photon.
So you can be a typical pass.
So this is the go this way.
At this point, you do need to do any more job.
Good news and bad news.
It got off its own.
So it's similar to stop here.
Another way to keep going is just go out of the surface and hit the detector or just move another way.
That's the island of the story.
Then you sign another photon.
You keep doing, you sign the million-gillin photon.
Then you can form a picture like this.
We once developed the fastest numerical simulator based on hydroheedron based in homogeneous monocalooptical simulator.
Got a feature that is good to see in the look with generator image.
This hydrogenia is animal with hard, long, sourced, sourced, and labor, stomach, spleen, kidney.
So quite a realistic.
Then you can light this bio-luminizing light source.
Keep emitting photons.
Then you form images, something like this.
Then you have a color bar.
Very nice work.
The first of the old, right now work is my work.
The next lecture I talk about machine learning.
My student, Qing-Sung, just got an outstanding offer from Google.
He's doing machine learning.
This is a very good area.
The scale side we learned really useful.
You can do a high-o, very nice work.
You see here.
And the quantitative level, you say the photon, the quantitative emotion, it will move not very long before it being scattered because the medium is highly scattering.
So on our reason, maybe this particular photon may go far, may go salt, but statistically, there is a terminology called mean free pass.
That's on our reason.
In this particular type of medium, the particular type of photon, we will propagate without scattering.
So this is called mean free pass.
Usually, older of 0.1 millimeter.
This is very small thing.
Below this limit, you call it ballastic region.
This keeps going.
But then it gets scattered, scattered away.
So originally, x3 imaging, y is good.
You have directional information.
You know it goes straight.
But the optical signal, it goes, little bit, it gets scattered around, it turns around away.
So a few turns.
The photon, old researcher, got totally confused.
Where the photon comes from.
I got a photon.
I do not know where the photon comes from.
Not like x3 photon.
I got a photon.
I know the x3 must follow this way.
But now I call it made.
A photon comes in.
It could be scattered from you or scattered from other places.

So the second concept, transport mean free pass.
And this is the world-class tidal.
That is our region lines.
After going through these lines, it's about 36 degree.
So that's the turn around.
You totally got this or the orientated.
You lose directional information.
You lose this information in simple words.
You do not know where photon comes from.
Then you cannot make an image.
So this is just the limitation.
So the typical transport mean free pass about 1 millimeter.
So optical imaging, within 1 millimeter, you can guide some reasonable result.
So you're beyond 1 millimeter.
You can now guide high-range, and you can use a motion imaging, so this is, you cannot guide high-range, and you can use a motion imaging, so this is, you cannot guide high-range, and you can use a very challenging, a really challenging, I wouldn't say totally impossible, but it is just the challenging.
And you can use a photo, a course date, you can use other ways later on, I mentioned some x3 optical coupling.
Just found the mental limitation.
Then they feel the optics, we have several imaging modalities.
And the idea, you can really see the end of the line of the idea.
First idea, they feel the optical spectrum, DOR, does, does usually all the computer operating systems for the does.
You know does, OK? Then you're not too young, you know does, OK? This one, we do not try to do imaging.
We just try to do analysis of all the overall thing.
This is my finger.
So the finger, so I have this device.
One side, I signed a polychromatic laser light.
This blue is right components.
So the blue and the right components go through the material, my finger.
It will be a tiny way to do it differently.
And the tiny way depends on, you do two measurements.
So maybe in this frequency band, in this frequency band, you go to two measurements.
Then you can solve two unknowns.
And we think the main thing, my finger, roughly, is the blood.
Blood in the viso micro-versiculture.
And in blood, you have two components.
And the blood shell, blood components, hemoglobin.
You have two kinds of hemoglobin.
When the oxygen reach is oxygen per, depending on their relative ratio, we know oxygen saturation.
So oxygen saturation, blood pressure.
All these are vital signs of life.
So I can use this small thing, put on finger, like a monitor oxygen saturation.
And for water components, this is blue thing.
And for oxygen per blood components, you have a tiny thing curve like this.
And for oxygen reach, hemoglobin, you have a right curve.
Right curve when the blue curve are different.
And so I do two measurements.
I can find relative contribution.
I must model here.
So the first measurement in this low frequency band.
So you use the optical titillation coefficient in the lower part here, the green right.
And this one we do measurement in high frequency part.
Pretty much like a dual energy CT imaging.
You have two material bases.
Then you do two measurement high frequency or high energy, low energy.
Here, high frequency, low frequency is the same thing.
So you have two measurement tools.

I know, and the measurement really combine the relative curve with the low frequency portion.
Here is a high frequency portion.
Very nice high school system of linear increase in these two unknowns.
You solve it.
You have the relative concentration of oxygen reach and oxygen per hemoglobin.
And you do commutations.
You can calculate oxygen saturation.
So this is just a treat the whole thing.
We don't want to resolve any pegs of it because this is highly diffused.
It's not easy.
So this is the one idea.
What's the dose? So in exact minute, you don't want to tell me it's all the PC operating system.
This is the, we are not doing CIS courses.
So this is the spectral imaging.
And second idea, this is used to slice the tiredly idea.
We want to do tomography.
You really want to do tomography.
So we want to do tomography in the same way we do x-ray tomography.
How you do x-ray of gamma ray tomography you should pencil B mode from kind of a line integral for nuclear imaging.
Guide line integral or something quasi line integral because line integral subject to a tenuous kernel.
But the kind of still information is along the line.
So you got one line integral measurement that's linear system equation.
Which all these unknown weighted according to intersection between beam pass and pegs of virtual shape.
That's a weighting factor, relative fraction.
So unknown times a weighting factor plus another weighting of a non-vacator, another unknown plus, not the other unknowns along the beam line.
That's one linear equation.
And you have many, many linear equations.
And the weighting factor can be known before imaging because you know the imaging geometry.
What's unknown is all these mules.
These pegs of values, x1, x2, are just a mu1, mu2.
So what is the same thing? And depending on imaging modality.
So for actually imaging modality, all these x1, x2, mu, linear tenuous coefficient, and what you measured along one pass is all these mu1, i.e. together after the weighting.
How you can compute that? Let's go back to be as low.
So you have in-carming intensity, it's a detractive intensity, output, equal to intensity, input, e, mu1, mu1.
So suppose you just go through one pegs of lines.
That's the delta.
This is the goes through one pegs of mu1.
And second of one, this is output, becomes input to the second of one.
This is mu2, so this is the type is mu2 delta.
And you have another one, you keep hiding.
All these I did together.
So in the x-pennential part, this will be minus sigma mu i delta.
So you'll notice this is what you measured.
This is what you are sending from the source.
So you do re-sou, so you got some unknown quantities.
So you just change to the other part, you can be right as sigma mu i delta equal to this i original.
This is output.
So just move this to the inside, do the re-sou.
You got this one.
If you do log, both sides, log, you purely get this mu i delta equal to i, i, i, i, o.
So all these are known.
So you know the sum, re-sum compute this way, depending on image modality.

So this is a review with concept like this.
I hope when you do job interview, you can just write how to like this.
So the analogy here, you say we send optical lights into the tissue, then these all these x optical tiny waves and co-efficient, some how.
But the lights do not go straight, just go all around.
So we never send single beam laser beam, and you do all these measurements.
And therefore each measurement really let go different way of tiny wave coding to the pass, the transferverse.
It's still a waiting factor.
So just all these things I did together, still linear equation.
It's still linear equation.
Just linear equation, if you send signal, no matter what you send, the light uniform led to view, that means all the equations are the same.
When the equation are same or very similar, you have difficulty time to solve.
Just keep tiny wave, x plus y plus z equal to 1.
Then I do another measurement, I will take it.
x plus y plus z equal to 1.001.
Then next one I say the sum equal to 0.999.
All around 1 plus noise, you feel very hard to solve what x y is.
So you have many measurement, true.
But because the fusion things make all the look same, so no information, no much information.
But researchers manage to say, the price, you price, the user, infride, light, relatively longer, like scattering, better penetration.
And you just still get signal, and you try to make some mathematical trick.
Then you try to recover all these in sexual reason, distribution, think, if you have tumor, then the sexual reason will be different.
Water, flaxen, and hemo-globing flaxen.
If you have cancer, hemo-globing will be rich, because cancer will need vasculature to support.
So all these arguments, try to make image many people are writing.
And these are nice work, under certain conditions, they do agree with experiment.
But the question remains, do you see any clinical really use this, not now? So they just keep doing for many years, still not mature.
Principle is there, but it is highly, so called ale pose.
It's not so stable, not to the degree.
You cannot do without like our x-ray imaging.
We're very proud of our x-ray imaging.
So any hospital, many modalities, and actually use the widely, and the somehow of technology, we divide it really in daily use.
You take it away, hospital will lose money, so just close the door.
And the evil hospital in clinic, you ask a doctor, you just keep, you only allow, keep one image in modality.
They will not select, I'm, I will not select, optical no outstretched, they will say, I'm back, you can ask a doctor, they will say, you want to keep x-ray.
So x-ray is very important.
Anyway, one way to improve the localization capability, and this is idea to temporal gating.
So the photons go all around, but if you do gating, you just collect signal early photon arrival.
For optical signal, the temporal resolution, the temporal resolution of detector is very good.
So you can do gating.
So the gating means the photon does not have time to go around, any photon you receive, is directly goes through, or subject to less number, limited number scattering.
So that means you kind of use early photon, you kind of get street rate.
So this is good idea called temporal gating.
This is a collimation, collimation mechanism.
What I already told you, mechanical collimation, I actually call it a meter, it's my technical way, it's just use some tube, so I actually go through.
And when I explain to you about the pattern imaging, you use electronic collimation, you just call it the decation circuit, and you have temporal

correlation.
So how you do correlation is interesting thing, how do you do it with twist, and I think I remember I mentioned to you, about some polarized radio-treature.
So that way you use magnetic collimation, you flip the, I'm back around, and you cheat with same effect.
Anyway, so the field of optical imaging is not easy.
So it's still a research topic, they leave early this year or last year, even my group will publish a paper about how you do optical tomography, better with some cutting-edge computational technology.
But this is not widely used yet, far from clinical use anyway.
So now, go back to fluorescence molecular tomography.
Fluorescence bioluminescence imaging are very important because you can use fluorescence and bioluminescence probe to label proteins, genes, drug delivery, so this is important.
And oftentimes we use small animal model.
Small animals as models of almost all human disease.
So we don't want to try on human, use small animal, and we make small animals, so we are not very nice.
So we make animal, get cancer, get a cutting-edge, lose bone quality, old troubles.
Then we try to treat.
Then we see if drug, first, if you think the principle and everything good, we need to produce promising results with small animal.
So you label cancer style, with say, right fluorescence.
Then we try to do some immunocerepate, which drug, they label in, say, green fluorescence.
If they come together, state together, then the cancer style died.
Then right light go away, and you can monitor in view.
So this is the idea.
So animal, hawing like this, is not a physiological good position.
Physiological good position should be lying down.
So this is not good design, but just so principle.
So inside the animal, suppose the cancer drug and the cancer style, are labeled, you have many types of fluorescence proteins, with different colors.
So you just say different colors, labeled here, but initially you see nothing.
And then from one view, you send the female second legion, certain wave lines send into most body.
Then this will induce fluorescence signals, it just send them, pause.
Then you do observation, the filter, the filter use, because I send in one color, what come out naturally will be a different color.
So the filter is there to block the transmission wave lines, only except the emission wave lines.
So what you have is a signal, so you got a signal.
So you have the view, one view, you just wrote a data animal, you got a different view, kind of CT scan, just CT scan, give you all the line integral data, but here you have the view, somehow the view, you have use some trick, but still the view, so the system is not so friendly for you to solve, stabler, accurately, uniquely, but you just try to collect data, waste ICCD, this is optical sensors.
So you got the image, the one view, mic, and some results claim, they can do recontroxen, and these are, I believe, good to certain degree, but not very reliable.
So this is one picture shows 3D recontroxen, waste color bars, so you can just get feeling, fluorescence, molecular tomography, recontroxen is 3D, so this is a practical image modality, not good for human.
One way, the fluorescence probes, and many of them, not good for use in human.
Second, human is much bigger, the optical light penetration depth, laser delivery, all limited, so this is mainly, practical image modality, and before joining RPI, I was faculty with Virginia Tech and WCA Forest University, medical school, engineering school, so I have laboratories in both campuses, and one project we got, multiple million dollars, so we say use optical molecular tomography to monitor vessel growth, so when you got cardiovascular disease, so you got a certain piece of vessel, really just got closed, blocked, and now you put stand, make it open, but stand is your own problem, so future cure, just

take the biodec segment out, put new biological vessel grow from your own stem cell, so how you grow the blood vessel, so we do it in bioreactor, so some device, so here you grow the vessel, the bioreactor, the nutritious liquid circulating, and see if the vessel grow well, you want to monitor it, so we insert OCT, OCT, give you an atomic structure, then you will see the laser, we see the laser light, and use the fluorescence, to do cellular molecular imaging, we see the indoor cellular layer of the vessel, you want to have the indoor cellular layer to make the vessel very good quality, so use fluorescence probe to monitor, so we do this imaging in bioreactor, so this is a project idea, use all the optical diffused components, and this is not very big, smaller than small animal, so you can get a little better penetration, and the resolution, OCT, give you structural information, optical diffused tomography, and the relay recovery, the optical property, once you know the structure and optical property, and you can use that as a prior information, to do fluorescence tomography, for this segment of vessel, for regenerative medicine, so this is what we did a number of years ago, okay? And this modality, and the walls derived by our lives, it do in bioluminescence tomography, I would argue bioluminescence tomography is the most challenging tomography problem, it has an all optical diffusing problem, and also, for fluorescence tomography, you can use laser from different directions, so this is an active imaging modality, bioluminescence tomography, like you get bioluminescence animal, you just put bioluminescence probe through biotechnology inside the animal, animal is just like a firefly, so you just see the light coming out, you cannot inject the laser anyway, so you do this to pass the rays of the rays, so you do not do active, like you can do collimation, you can do collimation, but you cannot do active stimulation, like actually shoot this way, that way, so for bioluminescence tomography, you just walk around, you see surface light, this is from four views, so this is water we see, you might live at that time, I walk with university of Iowa, in the dark room, we can see this, the question is based on these, and the can you, can you use this reconstruct bioluminescence self-distribution, there's a question, so we got multiple million dollars from NIH to devile, and my idea is to do multi-modality imaging, this small animal, so we do a micro CT, or micro MRI scan, so you have an atomic structure, you do segmentation, so you have this structure information, put it in finite element mesh, so you got this one, then you do optical, they feel the optical tomography, just sign the light, see the reflection, based on this couple of ways structure information, we infer the optical property of individual organs, tissue background, so we have optical map, we have an atomic map, we put together, this is detailed, pixel wise, precise, prior knowledge, so with this prior knowledge, you can imagine, I put a light source here, water will be the external measurement, use Monte Carlo simulation, like the simulator I saw you, so you put one, you just light the photon, suppose this is light source, you keep sending photon, it's not single photon, maybe 10,000 photon comes out, and the easy photon randomly go different directions, it's an actual tropical emission, and go transformation, reflection, diffraction, scattering, finally move the way out, and we register the signal, we take a signal, keep sending, so you put a source in any place, you can have a surface mic, you put any one, you can have a surface mic, so this is kind of like a point, it's very function, that means you gave a source, the revolution, you know water will be external measurement, and now we are dealing with inverse problem, you know this, distribution, water is the source, so simple thing, think about this, we just imagine the source is severe in the middle, then we do simulation, see if you have a severe in the middle, water will be external flux, it looks generated flux, looks not the same, I change the little bit, see if it might, the external measurement, little bit, you go back and then falls, and finally you see, okay, we have two bioluminescence sources, on top of life, and right kidney, it's a new miracle of the magician, then we kill the mouse, we see on top of kidney, you have two pieces of cancer, and then we did study, and one dedicated study published in optical x-surprise, and then we see good magic, it's a good case, but by the case, it do not match, so the trick is that, you need to have this very precise, an optical caracid region, very precise, and it's complicated to a degree, is not currently, it's not very attractive, and also, you got all these models, these looks right, but slightly model, makes the magic, we'll make the result, not very precise, so all these problems, it's an impregnable, it's

feasible, but it's not, again, it's not like an x-ray CT, you go, this is a scan, no question, it's not more chill, just a, research, IREA, we still want to post this forward, but anyway, this is just the idea about biolumination, biolumination, biolumination, biolumination is what we deviate, so we contributed a few phrases, like combing, helical, survival CT, interior tomography, this one, number of things, so this is pretty much, very, very, enjoyable doing research, another idea to make for the license tomography, and biolumination tomography better, is to hybrid the imaging, traditional x-ray CT is not the, the best, because traditional micro, micro CT do not show internal structure of soft tissue very well, so why idea is to use new technology, because the x-ray face contrast CT, that will show internal structure components better, and some result reported, this scan, data mouse for over a day, and use, is that of using micro CT, use gritting base, think I mentioned to you in Japan, I reported some of our work, gritting base, face contrast tomography, so this is some results, published by European, and at RPI, so we are trying to integrate a system for in vivo, so this is why for x-view, in vivo imaging, we basically put a orthogonal imaging chain for face contrast imaging, and I had optical imaging, to try to merge those things together, so this is still work going on, for very tight x-ray optical integration, and this again, research topic, to do 3D tomography, is a how you do 3D tomography, precisely, and stable is an open topic, and not will solve yet.

Last part, talk about x-ray optical coupling, and you see last two names, I-X-I-O-C-T-I-S-I-M-I-O-T, okay, so, it's a tomography material, reminds me of light eye mating proteins, one is pro-resens protein, the other is bioluminated protein, P-I introduced another animal, called Ninal phosphory, still Ninal particle, but it's not protein, it's just the engineering construct, so Ninal phosphory, Ninal phosphory, by nature of the material, if you suit x-ray, the Ninal phosphory will generate lumenized light, the same thing, like visible light, and you can make a different type of Ninal phosphory, generate green light, light, near infrared, far infrared, so you can generate light, it's very much in parallel, for fluorescence probes, so you send, you send laser light, okay, then the fluorescence probes, we will generate lumen fluorescence, here you send x-ray, K-T-N-O phosphory, N-O phosphory will emit lumenized light, this is in parallel, but the difference lies in the way of stimulation, and you send the laser light, laser is light, okay, so it will subject to diffusion, but x-ray goes straight, so the dive is resolution is much better than optical stimulation, so this is an article, and it's x-I-O-CT, x-3 lumenizing CT, the essential idea is shown here, so you have Ninal phosphory introduced into small animals, so N-O phosphory can be functionalized, potentially, and with some polymer surface, on the surface, you can couple that with some peptides, the peptides will help you target biomarkers, so you know if this works well, the N-O phosphory will be accumulated, richer, nearly richer, you want to image like a cancer cell, then you suit x-ray, and x-ray goes straight away, if along the x-ray region, the light comes out, you know there are some cancer cells there, so this makes x-ray potentially molecular imaging modality, so here you send x-ray beam, you use collimation, so you treat x-ray as particles, you collimate, then a limitation, is not, when you collimate x-ray, and the mechanical thing and the manufacturers, you cannot make it too thin, and you make a thin beam, then x-ray goes out, it will be spreading out, because x-ray also subject to compensatory, so as a result, this x-I-O-C-T, x-I-O-C-T, the resolution is about 1 to 2 millimeter, how can you improve the special resolution from 1 to 2 millimeter, say improve an older magnitude, say 100 microns, how you make it, so we wrote people, this is x-ray micromodulated luminizing tomography, x-m-l-t, and if you really interested, you can read article, basically we treat x-ray as wave, so we can use some x-ray optics components on market, say x-ray polycapillary lines, so you send x-ray into the lines, x-ray will be focused, it's not like an optical lines, you cannot do it dramatically, only you do it to a certain degree, but you can indeed focus actually beam onto a spot, about 100 microns or even lines, and you can do so deeply, because x-ray can penetrate easily, so this way you'll do focusing, you'll do optical measurement, so you know you got a lot of data, and it will be for only from this x-ray pass, because the outside, you didn't excite, you do that half signal, you have an optical signal, but the resolution is defined by x-ray beam, particularly by this focus ball, so you think focus ball is actually coming, so you got a comb beam, vertex is a

focus ball, it goes out, this double cone excitation, so you can do x-ray tomography, but really we collect optical signal, not in pencil beam, not in fan beam comb, really we are doing imaging in double cone geometry, so we have paper, several paper about this, so we are in collaboration with general electrical sink, you can do micro focus beam to excite 904s in small animals, so brain imaging, like a comb out, like a comb out will be reflected in this integrated sphere, like a photon comb, this is very good reflector, only one opening, so the photon could go this way, then reflect here, here, here, here, here, anyway, if it wants to reach this detector, I'm sure the photon will keep moving until going to the detector, so we collect all the photons, so this is the way to do small animal imaging, we can also do human imaging, optical imaging, the limitation I say, you got good resolution, 1 millimeter, as I mentioned, 1 millimeter, human cortical layer, about six layers, the total second is about six millimeter, so how you got human brain, the intelligence things, out of all layers, not in the surface layer, and the deeper layer, as you can imagine, is more important, so one possible channel, uses small nanofossophores, label certain things, then use the focus of the beam, micro focus of the beam shown here, to light nanofossophores, then when you think, the generate x-in-potentials, x-in-potentials are current, so the current passing through nanofossophores, and by quantum mechanics, the nanofossophores, the light I made by nanofossophores, will be changed, so color change, you know what's going on, what you are thinking, so this is the kind of scientific fiction, so this is the idea we are pursuing, we are not having much to resolve, this is something, x-re-optical, nanofossophores are coupling very cool, another thing I want to mention, cool technology, optical genetics, so you'll sign the different color light, depends on wavelengths, you can open or close on channel, so you can control new rock, so you show like moving, you sign certain light, and the swarm will go one way, change the color, it will go the other way, so you can control, this is controlled model to study some very difficult disease like depression, you do not have a model, but you need to use things like this to do very specific manipulation, and then again, optical genetics, optical control only up to one millimeter, not very deep, okay? And if you want to do deeper layer stimulation, you can use, introduce optical fiber, but that is immersive, okay? That's immersive, so my idea, and my student and I wrote, x-optogenetics, the idea is to introduce nanofossophores, so this is a nanofossophores so small, goes through blood-brined barrier, so this is beauty, say in, mouse-brined, then you just focus the actually deep, to light it up, so this way you have full control, so the studio, you still do optical genetics, operations, but it goes through x-3 execution, with a middle man called nanofossophores, so this is my student, this is second-user, really co-first-user, second-user is my, first-user is my undergraduate student, he's still working on this, we got suppliers of nanofossophores, we are doing, at this stage, we are doing nanofossophores characterization, this will be very cool as well, so last slide, hold more, this is, I think more typical, you'll review this lecture, summarise, not summary, summarise key ideas and points, so if you are licensed very carefully, and you should be able to follow, you can review the video recorder, and this is more, crisis thing, if you like, you do, you send, you'll result to me, you can, transcript the first part, second part, or last two part of this lecture, just put it down, and this is just a review process, and I will edit, again, this green or optional thing, you can think, I mentioned smartphone, can be made, a ultrasound transducer, also, smartphone can be made, a optical image, so you, smartphone can sign the light, like you can already sign the light, then you can detect the light, do some analysis, this is supposed, use smartphone, future smartphone, can sign, or receive light, anyway you want, certainly subject to physical feasibility, what medical imaging applications, could you imagine, and I kind of hinted, I like most, I want to use this, send light, or maybe polarize light, you can guide, maybe llama, llama, I didn't mention, llama scattering some fancy mechanism, we could, I don't know, but I pretty much hope, it will immediately give me a lot of sugar, or use this, to guide the oxygen concentration, so all these things could be done, potentially, anyway, so much for today.