Charles S. Peskin & David McQueen Oral History

COMPUTERWORLD HONORS PROGRAM INTERNATIONAL ARCHIVES

Transcript of a Video History Interview with Charles S. Peskin & David McQueen

Recipients of the 1994 Cray Leadership Award For Breakthrough Computational Science

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JE: I wanted to get you to talk about your backgrounds, which are kind of unusual. Both of you were involved in engineering and applied physics that sort of thing and then suddenly on your vitae shows up medical training. Can you in any order tell us a little bit about how that came about?

DM: You want an honest answer, right?

JE: Sure.

DM: Okay. I was working for ESSO research and engineering as a mechanical engineer. They were having lay-offs and I was one of the people laid-off. When I went back to my college to use their placement office, Stevens Institute, one of my former faculty members said, "You should go down and talk to Mike Cohen who was one of my old professors. He's doing some very interesting work." So I went down and found that he had changed his interests from heat conduction and chemical reactions and that sort of thing to working on applying engineering principles to problems that arose in medicine, and he said, "You're out of work. Good, you want to come and work for me." He offered me a position and the work looked really interesting all of a sudden, compared with the work that I had been doing at ESSO, which wasn't so interesting. That's how I sort of got started on this road. We were interested in studying the physics underlying the measurement of blood pressure with a cuff and a stethoscope. It's a short trip from getting interested in that problem to getting interested in blood flow in the heart.

JE: You suggested earlier that no one really knows what happens in detail when you are taking a blood pressure measurement.

DM: That's right.

JE: Have you had any luck in solving that problem?

DM: Well it turned out to be a very difficult problem. This problem has been worked on now for close to a hundred years, since Carrotcoff first made his observation that you appeared to be able to measure blood pressure indirectly by constricting the blood flow in the artery and then listening to the arm with a stethoscope. During that time there had been more than a dozen distinct different theories advanced for explaining what causes the sounds in detail. It seemed to me, after trying to make sense out of all of it, that the only way you could really make a judgment to which if any of these was on target, was by making a direct measurement of what's actually going on under the cuff. This turned out to be a lot harder than I had expected it to be.

We spent close to two years simply trying to make a measurement of what the arterial wall does during a blood pressure estimation. The technology just simply wasn't up to it. We realized what advance in technology would be necessary, but it was beyond our capabilities as a small basically mechanical engineering laboratory to make that huge leap in the ultrasonic technology that we were using to try to get a better measurement of what the artery wall was doing, and we had to give it up.

JE: But, you were hooked. In spite of that you were pointed down the road toward medical mathematics, or whatever you want to call it.

DM: Well, they're very interesting problems.

JE: Did you have a similar experience?

CP: No, I would say it was different. As an undergraduate I was studying engineering, electrical engineering mostly, and applied physics. And, I think I liked physics courses best. I really liked the idea that you would take a physical situation and write down some equations to describe it. My freshman physics course was where we learned how to do that, and that process really fascinated me. The idea that you could capture reality in a system of equations and then learn more about it by studying it. Somehow, I also wanted to apply it to biology. It seemed to me that biological systems were the most interesting.

You know, engineers like design, and nature's design is always better than anything people can design and it's fun to try to contemplate nature's design and pretend that you were designing it, think about how you would do it, and then compare that to how nature does it. I wanted to apply these engineering principles and physics principles to biological systems. But, I didn't know what I was going to apply it to. In fact I guess if you had asked me in college what I was going to do, I thought I was going to study memory. I was fascinated with the idea of how memory works.

So, then I went to medical school with the idea of learning more about these biological things, to try to get the feel for it to understand it more deeply so that I could do it. I also had some idea that I might practice medicine; I thought I might like that too. I learned in medical school that I wouldn't like practicing medicine but on the other hand that the other motivation was a good one. Medical school was a good place to get a sense of what's important and how biological systems work and, get hooked on interesting problems. I never even thought about the heart before going to medical school. In an undergraduate education the heart doesn't come up. It's a medical subject. But, I got really interested in that and it seemed like a good case because it's very physics dominated and I like physics and it seemed like enough was known to deal with it. The basic laws governing the heart are Newton's Law's and we know Newton's Law's.

In other biological problems one was faced more with the unknown. You couldn't just write down equations, because you didn't know what was going on. So, for that reason the heart was attractive.

JE: Was it a total coincidence that you both did work at Albert Einstein College of Medicine?

CP: Yes, because I met you after you worked at Einstein, if I remember right.

DM: No, actually...

CP: I'm sorry not true.

DM: We met because your father invited you to come. Your father suggested to Mike Cohen that it would be good if you visited and I think he must have suggested to you that it would be interesting to you to come visit Mike Cohen's lab.

CP: Right.

DM: That was in, I think in 1973. It was before you taught the first course on mathematical physiology of the heart.

JE: And you were in Cohen's lab at that time?

DM: I was in Cohen's lab at that time. Right.

JE: So, that was around...?

DM: That was in 1973. I think the coincidence was that Cohen knew Yellin independently of you.

CP: That's true.

DM: I think that he had met him at one of the alliance meetings.

CP: So, actually there were two, I mean just in terms of things happening by chance, there were two things that happened by chance which were crucial for me getting into this field. One was, that a student who was working with Yellin somehow realized what my interests were and said "Why don't you come work with us in the summer. Y'know I think Yellin will have a job for you in the summer." Before then I hadn't really thought about working on the heart but it seemed like a good summer job, so why not do it and then I kind of got hooked on it.

The other thing was once I got interested in that problem, I needed to learn fluid mechanics, which I had never studied. It's quite striking that while I got a terrific education in college that physiology, which I did take a course in was like the worst I ever did in a course. I think maybe I did worse in English once, but physiology was one of the worst courses I took. I never studied fluid mechanics and I never studied computing in college. So the things I do most are things that I somehow learned afterwards. But anyway, I needed to learn fluid mechanics. So I was sort of wondering "How am I going to learn fluid mechanics? If I want to do this heart stuff I'm going to have to learn fluid mechanics."

Then, while I was visiting some Russian cousins of mine, elderly Russian cousins. They had a close family friend who was a professor at NYU named Alexandre Chorin. He was a young guy at the time, just gotten his Ph.D., just starting out. And I asked him "Do you know where I can go to learn fluid mechanics?" and he said "Come study with me, I am the best" and it turned out that it was absolutely true, absolutely true. He got me started with numerical methods. His field was computational methods for fluid mechanics, numerical analysis fluid mechanics. So, I learned both fluid mechanics and computational methods from him. And his method has been kind of the mainstay, y'know it's a key ingredient in our method for the heart.

JE: Are these numerical solutions to differential equations?

CP: Yes, specifically to the fluid mechanics equations. The methods he developed actually in his PhD thesis we used in the heart code. So, I had actually two people who were very important, Yellin, from the biological side, although he was a mechanical engineer by training so he also had this mixed point of view. But anyway, Yellin from the experimental side I should say and Chorin from the mathematical side.

JE: And these people are where?

CP: Yellin was and still is at Albert Einstein Medical School in New York, which is where I was a student. And Chorin was at NYU and he's now at Berkeley. But, when I was at Einstein he was at NYU and I went and took his course in fluid mechanics and that's kind of how I got started on the theoretical side.

JE: And the man you were working for is also at NYU was he...

DM: No, it wasn't at NYU, Stevens Institute. I did my PhD work at Stevens Institute and my advisor knew Ed Yellin.

JE: Oh, okay that's it. I was looking for that specific connection.

CP: By the way another thing Dave mentioned is that my father played a role in this because he was at Stevens and actually when I was in college he was telling me "Take some Biology, it will be interesting. You'll like it, y'know maybe you'll want to combine them". I think it was sort of his idea that I might somehow combine biology and engineering. He was an electrical engineer he also taught me an important principle that electrical engineers can do anything. And I think he thought that I might do something of this nature, I don't know what made him think that but it was a good idea.

JE: Okay, so you both got set in this direction, how do you get from where we just left you which was at Albert Einstein and Stevens to the Courant Institute are there any direct paths or did it take a while?

DM: Yes, for me there are.

CP: Since I got there first, let me answer first. Well, I mentioned how I met Chorin through my cousins and he was a professor at Courant. So, when I was doing my thesis at first I sort of had a balanced experimental, computational program. I was building physical models to look like the heart, to study the flow through heart valves, make movies actually, put particles in the fluid and watch how they go through, and stuff like that.

So, I did some experimental stuff and I thought the thesis might be experimental or it might be computational, or it might be a mix of the two, I didn't really know how things would go. But somehow the computational side got more and more interesting to me and I started doing more and more of that. And, Chorin was the expert on that so that I did a significant amount of my work on my thesis at the Courant Institute. They were very nice, they let me use the computer and they gave me an office for part of the time I was there and gave me all kinds of help. So it was almost in some ways as though I was a student there. And actually Chorin and I think Peter Lax came to my thesis defense. So, they had an interest in me while I was a student. Then they started talking about when I got my degree, they were saying that they might like to hire me. But, I was still in this M.D. Ph.D. program so I was supposed to do the clinical part of medical school.

I started doing the clinical part of medical school, and I didn't like it, it was terrible, I wasn't good at it and I hated the feeling of drawing blood and hurting people because I couldn't do it right, and I didn't like being up all night and just... it was very clear that it was not for me. So, I rather quickly in fact very quickly after just like a week or so, dropped out of that program. But, I asked them if I could spend some time staying in the program but not as an M.D. student, just stay in the program to hang around the hospital and learn things. That was very valuable.

The best thing I did was pediatric cardiology and I just went on rounds with them and I talked with them and got a sense for what some of the problems were and I've actually done some work in that field modeling those things since. And as soon as I was no longer responsible for dealing with patient care, I was fascinated. I liked the process, but from a distance a little bit so I spent some time after the Ph.D. observing in the hospital to learn what some of the interesting problems are. But, then I also was worried about my future so I asked the people at Courant who offered me the job, did they care that I wasn't getting the M.D., I wasn't sure maybe they liked the idea of hiring an M.D. I didn't know. But, they said no, it was okay, they would still hire me. So, to answer your question about how I got into Courant, they knew me already because I was, in part a graduate student there unofficially, and they liked what I was doing so they wanted to hire me. So, I came there and then how Dave came, you can answer, but in part from my side, I gave a course and he came and took the course.

JE: So, there you are at Stevens, while he's doing this stuff and still interested in the medical problems

DM: Yes, I'm still working on my thesis but my advisor believed strongly that it was a good idea too; he felt a certain amount of inter-disciplinary work was really essential to making this medical engineering work. You wouldn't get reasonable results as an engineer working on these kinds of problems if you didn't understand the other guy's field of knowledge and most importantly as far as he was concerned you had to speak their language, because they weren't going to speak your language. So, he encouraged us to look outside of Stevens for course work that might be appropriate and made us take physiology courses and he also recommended that Charlie's course on the mathematical physiology of the heart might be very interesting, which it was.

So, as a graduate student I was seeing some of the stuff that Charlie was working on at the time. When I finally graduated, got my degree, Cohen suggested that a post-doctoral period would be a good idea, that it would solidify my understanding of physiological type problems if I spent some time at someplace like the Albert Einstein College of medicine, where by chance he had a friend. I was able to spend a year with Ed Yellin at Einstein and at the end of that year I had to decide what I was going to do and by good fortune Charlie was looking for someone to work on this project. He had funds for a position and the chance to work on this stuff at the Courant was really wonderful, it looked like it would combine all of my interests. And I've been there since.

JE: When you say it was this project, at some point you decided to do a simulation, is that right?

CP: Right, well my thesis was already doing this kind of simulation only it was much more primitive at that time. But, the method was already in use and was being applied to heart valves. I think in the thesis I got as far as a two-dimensional heart model with a very primitive atrium with a circular arc for the atrium, circular arc for the ventricle, and two valve leaflets in between. Not much of the anatomy, but two valve leaflets in between. So the whole project that David and I have been doing since then was already started in my Ph.D. thesis so sometimes I like to say well I'm still doing my thesis, just finishing it, y'know we're not quite done.

JE: When you talk about a mathematical model of the whole heart there are a number of things that come to mind, I mean you could do fluid flow equations for various parts but it sounds as though what you're doing ends up to where you're modeling the whole heart all the walls, Is that correct?

CP: Right, it's a mechanical model, I mean a complete model of the heart would be more than what we do it would include the electrical properties of the heart. We don't do that yet, we may someday but what we have is a complete mechanical model of the heart. So what it does include is the fluid mechanics, coupled to the muscle mechanics of the walls, coupled to the elastic mechanics of the heart valve rethorts. All that is in there and the anatomy representation is quite detailed and quite realistic we think. What I mean by that is, that we try to arrange the fibers in space in the way that real muscle fibers are arranged, or in the case of the valves we try to arrange the collagen fibers that give the valves their strength in the way that the real collagen fibers are arranged.

JE: So you have what, a set of sort of mathematical fibers?

CP: Yes, that's exactly right. What the model consists of is some number, some large number, do you remember the number?

DM: The number of fibers?... About three thousand.

CP: Three thousand fibers and each one is like a rubber band, a closed curve in space, and it begins and ends somewhere on a valve ring. That's the description of the heart introduced by Carolyn Thomas who studied the anatomy in great detail in the late nineteen fifties, all the fibers begin and end somewhere on the valve ring and follow some complicated spiral path through space. And like I said before they're like rubber bands except there's one way in which they're different they're muscular so they can actively contract. They're not just rubber bands but these are active elastic materials and what that means in practice is their elastic properties change in time so when the heart is contracted it is very stiff and resting lights are short.

When it's relaxed it's more stretchy and the resting lights are longer so it's like an elastic material whose elastic parameters are time dependent.

JE: But you don't have an equation of three thousand simultaneous equations, right? I mean you can't...

CP: Yes, yes!

JE: Is that what it is?

CP: Yes, in fact much more than that. Three thousand is the number of fibers but each fiber has some large number of points on it, hundreds of points.

DM: We've got about a half a million points on the model.

CP: So it's like half a million simultaneous equations or something of that nature.

JE: To which you're doing numerical solutions?

CP: Yeah, absolutely. I can describe a little bit what the model is like. We start really from the fluid equations. So we write down the Navier-Stokes equations, which are the equations of a viscous incompressible fluid. Then we put in additional terms representing the forces, which the fibers exert wherever the fibers happen to be. So, the heart wall is viewed somehow, you could think of it almost like part of the fluid, that's the point of view we take. It's a part of the fluid where extra forces are applied which come from the fibers, fiber generated forces. So we treat the fibers as a kind of force field imposed on the fluid and that gives the influence of the fibers on the fluid and then the fluid carries the fibers along with it. So that gives the influence of the fluid on the fibers. So it's a two-way interaction, they each influence each other. So you used the right word when you said simultaneous equations, we're simultaneously solving the fluid mechanics and the elasticity problem.

JE: Boy, this really gives a whole new dimension to the word challenge! Aside from the enormous challenge, when you get it done what will you be able to do with it. Why essentially do you want to do it? It's an incredible feat.

CP: Right, it's not only because it's there.

JE: I didn't say it was... that is a perfectly worthy goal.

CP: The original motivation was to help design artificial heart valves, clear-cut, that was the purpose. People have been using artificial valves since 1960 roughly and one would like to test them without building them, to just test an idea.

So if someone has an idea for a valve they can test it on the computer and see how it functions. At first I thought of that problem in terms of the valve itself and the fluid but sort of gradually came to realize that it was important that the valve is in a heart, that it matters it shouldn't be just sort of in a rigid walled chamber or something like that.

CP: So originally the project was "Can we simulate a heart valve?" and it grew into "Can we simulate a heart valve in a heart?" and so the idea was to do what we call parametric studies on a heart valve design, which means you have a basic concept of a design but it has some parameter like a curvature and you just run a whole series of different curvatures and see what effect curvature has and try to pick the optimum curvature. Now we actually did studies like this in an earlier version of the model, which was a two-dimensional heart model. So we made a quite realistic two-dimensional left heart model. Two-dimensional, so it was like a cross section of the heart and we kind of picked a plane, which was roughly a plane of symmetry for the valve that we were interested in.

JE: Simplified the math.

CP: Yeah, right. Well as a way of getting away as best you could, with using only one plane. If you pick a plane of symmetry it's still not perfectly correct but it's better than just picking some arbitrary plane. So we picked the plane of symmetry for the mitral valve and we studied the natural mitral valve and a whole series of artificial valves in the computer model. We did the kind of parametric studies that I was talking about, and it did lead to one new idea, which we patented, and we're in the process of seeking a company to develop. And that had to do with taking an existing good design which is called the St. Jude valve. It has two flat rigid leaflets and in the computer we found that we could improve the valve by curving the leaflets. And not just the general idea of curving but we found how much it should be curved. We also found the best place to pivot it and that leads to an optimal design. So that was done on a two dimensional model and depending on your point of view you can question whether that's adequate for being confident in the design or not.

Actually I had a funny experience with that. As long as I was doing two-dimensional models people tended to look at me funny y'know "You're designing a heart valve in a two-dimensional model?" And there is a famous mathematician very nice guy named Mark Kac. I got into a taxicab with him and a group of people and he said "Ah, Peskin. The man with the two-dimensional heart." So people started making fun of me giving me a hard time about that two-dimensional heart and the very first time I presented a three-dimensional heart in a talk someone in the audience, I also presented the two-dimensional work, and someone in the audience said "The 2-D heart looks so good why do you need 3-D?" So people are divided on the question of whether a 2-D model is adequate for the applications that we were trying to use it for.

My own point of view is that we don't know really whether it was adequate or not, we'll find out when we have the 3-D model working and can compare the two. But since we made a very definite switch to doing the 3-D model we're not using the 2-D model anymore.

JE: When was it that you switched, do you remember?

CP: It's been quite a number of years now.

DM: It was around 1983 or 1984.

CP: So, about ten years. And it was a real commitment putting all of our resources toward working in 3-D. The 3-D model is still under development and not quite ready for these kinds of applications that I had mentioned but we hope that it will be soon.

JE: How do you set up a project at the Courant? Do you say, "Hey, I want to do a 2-D model of the heart." Can I have x years to do it and so many dollars?"

CP: The dollars part is the crucial part of your question and the answer is you apply for a grant. As far as what a professor can do, a professor at I think most universities or at least at the Courant Institute at NYU you're certainly free to do what you want. There's no supervisor looking over you're shoulder and checking up on what you're doing, you just do what you like. But if you want a project, the definition of a project would be something like having another person maybe, Dave being part of a project. So if you want a project you have to apply for funds for it and I did apply for funds and this project was supported by NIH for many years and it has not been easy, we have lost funding twice. The first time we got it back after a year and then the second time we didn't get it back. So we then went to NSF and now we have NSF funding it. So we're sort of okay for the minute but that's a constant worry actually, to keep it going. But so far good times and bad we've managed to keep the project moving ahead.

JE: How does it work in your partnership do you divide up the work, or do you each take a certain number of equations, or what?

DM: Well the division as I see it is in a sense theoretical verses actual lines of code. In general Charlie comes up with equations and expresses them in a form that is suitable for reducing to a program, then I reduce it to a program, run the program get the results, try to make sense out of them and if I think I can make sense out of them I proceed in a sensible way. When it looks like I can't make sense out of them I say, "Charlie, I can't make sense out of this what do you think?"

CP: At the moment we're in to details. We think we have the basic setup right so the latest thing we do is a result comes in we look at it, and we both talk about what we do next.

JE: Do you code in any language, or do you like C...

DM: I hate C. The programs are written in FORTRAN . FORTRAN is...

JE: The real scientists language.

DM: No, I want to give a straight answer to the question. Not one of these provocative, religious answers. FORTRAN is especially suited for doing these types of problems on the Cray type computer because Cray's version of FORTRAN has constructions that make it easy to take advantage of the vector hardware and even the parallel. Whereas C doesn't quite understand what an array is and hence what a vector is, it can't, interestingly enough, take as good an advantage of the vector hardware as a FORTRAN program can. You the programmer have to work a lot harder to get a C program to vectorize than to get a FORTRAN program to vectorize. Plus many of the things that make C such a desirable language aren't the kinds of features were looking for. So we do everything in FORTRAN basically.

JE: Because of the enormous difficulty of the thing you go automatically for the most powerful computer you can get your hands on, right?

CP: Right, absolutely. That is definitely our philosophy. We've often used computers sort of in an early stage before they were available to anyone else.

JE: When did the C-90 become available to you?

DM: A little more than a year ago.

CP: What were we called, friendly... friendly users.

DM: Friendly users! That's right.

CP: That's the latest example of what I was thinking of where we were among the first to use it. There was a period of about a month or two, something like that. When we had access to it, and we weren't the only friendly users, there was a group of people who were given the friendly user status.

JE: Where is this machine physically, which center.

CP+DM: Pittsburgh

JE: You list all of the machines you've used has it all been pretty much Pittsburgh.

CP: No, we started on Cray's in Minnesota. Minnesota was originally an NSF center but it lost that status at some point. It was one of the pilot centers and it didn't make the transition to a full center. So we were at Minnesota when it was originally an NSF center. We were able to stay there for a while, when we had money from an NIH grant to buy our own time. But when we lost our grant we couldn't continue to do that. But the NSF centers are nice in that you don't need dollars you just apply for time. So, that's when we made the transition to Pittsburgh. But we got started on Cray's on the Cray 1 at Minnesota and the Cray 2 at Minnesota and then we moved to Pittsburgh when they had a YMP.

DM: That's right, but we've used other places as well. We spent a brief period of time at NCSA at Champagne-Urbana. And the National Cancer Institute had a YMP also that we used for about six months.

JE: How do you do this do you have a workstation and send your program in with the workstation and then set them up and put your parameters in and start off the machine and then it reports back to you?

DM: Well the workstation is just a terminal in this process you log on to the remote computer and do almost everything there and then submit the job.

JE: So you're working as a timeshare station where you log on.

DM: Yes, when you log on to the Cray it looks like an extremely slow shared workstation.

CP: Slow because there are so many users.

DM: There are so many users and the network connection is very erratic. Sometimes it's very fast, sometimes it's painfully slow. So, what you really tend to do is do as much work locally as you can to prepare the files that you want to submit and then you log on to the Cray and get the files that you need from your local machine and submit the job because trying to do anything too interactive on the Cray is hard. It's painfully slow sometimes and very annoying.

CP: I'd just like to make the point however that I think that is not an inevitable feature of that mode of operation it's simply a question of the balance of resources if the NSF center has another couple of C-90's put in at each center the situation would be different. I don't think it's inherent in that mode of computing, it depends on how much resources have been put into the network and the machines at the far end relative to how many users are there.

JE: And your local machine is what?

DM: It's an Iris workstation.

CP: So, actually when you were describing the process, an important part you didn't mention was that when the job is done we get back files to look at and then the workstation becomes much more than a terminal and that's why it's an SGI machine then we use it's graphics features to look at the results.

JE: The terminal puts results on the screen as graphics. Do you get a graphics file back, or do you get number files and then translate them there.

DM: That’s right we get tables of numbers basically which we then visualize with programs we've written that take advantage of the Iris' graphics library.

CP: Yeah, Dave wrote it. You were asking about the division of labor, Dave wrote our graphics software. It's a different problem from the usual we don't have surfaces, we're not interested really in rendering surfaces the way people usually do for 3-D graphics we want to really look through the surface to see what's going on in the interior. And there are a lot of differences when a thing is deforming, just to give one simple example which is striking in me. There's this great technique for seeing things in 3-D which is you rotate them and the brain does a really good job of reconstructing what the 3-D is when you see it turning and it even works for a random pattern of dots you don't need any other cues other than the rotation. But it doesn't work when the stuff is moving at the same time.

JE: Oh really!

CP: It just doesn't work. If it's deforming and you try to rotate it, it's just confusing you don't see the 3-D it just doesn't work. So, we have special problems because it's a heart, it's fluid it's moving around, it's deforming like crazy, there is no nice perspective because there aren't straight lines and stuff like that to act as cues. So, it's a tough graphics problem, and anyway Dave wrote the software that we use.
DM: Yeah, there's no third party stuff that we've been able to find that handles a problem with this much difficulty.

JE: That's such an incredible problem!

CP: The jump from 2-D to 3-D was a big jump in many ways but one of the ways is that just seeing what you've done is much harder. In 2-D seeing what you've done was no problem at all. In 3-D it's always a challenge y'know "Exactly what are we looking at here?"

JE: I suppose you're always improving your graphics programming or whatever, but when did you get it to the point that it was usable?

DM: Around 1985 or 1986 I think. We've always had some kind of visualization tool even when we were doing the 2-D model. But the 2-D visualization is a lot simpler because you don't have to worry about how your going to look at the data, it's all right there on the paper so to speak. Everything that takes place takes place on the plane just show everything that's happening and you're done.

CP: That's still our style, to just show everything we don't embellish. Just show what's there and don't add anything to it. Don't render for example we don't render surfaces, for the most part.

JE: Well is it wire-frame?

CP: Yes, the fibers are drawn as lines, period.

JE: Well, that makes a lot of sense.

DM: It turns out that to render that thing as a surface even if we wanted to is an exceedingly difficult problem, for which I've only been able to come up with one bad solution, very, very computational intensive solution. So, we don't render as surfaces just because it's difficult.

JE: But, at the same time it makes a lot of sense. How close do your mathematical fibers, intentionally or whatever approximate the actual muscle fibers?

CP: We followed this particular paper of Carolyn Thomas' and we follow her ideas. Now, her ideas are qualitative and she made drawings and we tried to capture what we thought was the essence of those drawings. So, it's that kind, it's qualitative y'know it's not a quantitative thing. But, we did the best we could to capture what appeared to be that. There is a way I'd like to do this, which we've only done for part of the heart, but I'm very proud of it for that particular part. That is to actually have a theory of the anatomy, a mathematical theory which would explain the anatomy. We did that for the aortic valve, so what we did was we started from the observation that the aortic valve is supported by really a one parameter family of fibers.

It's sort of the extreme of an anti-sotropic (sp) material, it's got very great strength in one direction and very little strength in the other. So, we just stated the problem what's the equilibrium of a one parameter family of fibers supporting a pressure load, and that leads to a partial differential equation and we solved it numerically and to our amazement the solution is not what you would expect from a partial differential equation, y'know a nice smooth solution but the fibers sort of roll up and form a complicated structure I call a branching braided structure.

And it looks like the real thing, the collagen fibers actually do branch and braid in that way. So, it looks like a really good theory and....

JE: Either that, or a lucky one.

CP: Right, or a lucky one. So, we used that for that particular valve. Of the four valves there are two like that in the model and that's what I would like to do that for the whole heart. We also have a theory, which we haven't used quite, but we have something like that for the left ventricle. The left ventricle is symmetric and therefore easier, the right ventricle is crescent shaped and therefore harder. So, our goal is to have such a theory for the whole heart, and to generate a heart that way, using a computer model. But, we have only done it in a partial way the rest of it; what we do is much more ad hoc. Imitating what we've found as best we can. But it's still quite a detailed model compared to what most people would try. Y'know a more typical model would be the heart as an ellipse or maybe there are no fibers or maybe they all run in rings. Y'know people don't typically, I'm not saying we're absolutely unique.

JE: Well they perhaps make large-scale simplifications, so you don't have fifty-five thousand equations or whatever you guys have.

CP: There is one other group that I can think of, I don't want to make a stronger claim, there is one other group that I can think of that models the heart fibers and does finite element model of the wall, but they're not doing fluid mechanics also. But they do take the fiber orientation into account. But, then other people who either don't take the fiber orientation into account or if they do they make the heart a cylinder and then have spiraling fibers on the cylinder, that kind of thing. So we try to be realistic.

JE: Did you try to make a number of simplified assumptions or have you just sort of gone at it mostly?

CP: Well we tried to put everything in that's feasible to put in, that's real but within reason. The fluid for instance we modeled as a newtonian fluid where as blood is strictly speaking non-newtonian. It's said and I believe that in large vessels the non-newtonianess is not very important. So, there certainly are simplifying assumptions that we make, every model makes simplifying assumptions. But, we do our best to make it as realistic as we can.

JE: Do you have sort of a hope for an end point, I know it's impossible to sort of even vaguely guess about that, but do you have sort of a sense that you see light at the end of the tunnel?

CP: Yes, we're very close to an important milestone which would be to have a complete 3-D heart model, by complete I mean all four chambers, all four valves, and physiologically correct. We already have a complete heart model but it's not physiologically correct, that is some of the valves leak and some of the pressures are wrong, too big, change too fast y'know things like that. So, it's complete but it's not tuned up yet, and we're in the process of tuning it up. And in particular the valves may be a tough problem, because the valves are leaky and we have to adjust them to get them to work.

Then when that happens, when we reach that milestone, which I hope will be soon. Then the model will really be ready for the kinds of applications which I mentioned before. Hopefully a heart valve company will use it for a test chamber for designing valves for example. You can study the functions of the heart and study heart diseases and start doing applied things again as we did before in the 2-D heart model. We have experience in doing that kind of applied work, but we want to do it now in a more realistic setting. Then there will still be plenty of room for improvements in the model but it will be good enough that it can be used, and then we'll be in a mode where we're both using and improving. Where as now we're just improving and not really using it.

JE: Anything that occurs to you that we haven't covered or that you would like to say?

CP: We need more computer power.

DM: My very thought. Bigger and faster is better.

CP: The NSF national computer centers are essential to this work and if each of those centers had twice as many, or four times as many, or eight times as many big computers it would be better and it would make a big difference. At the moment our pace is limited by our access to the computer, we have jobs queued up and waiting around and other people are using the machine. If we could get the job done faster we could perfect the heart model and use it for these important applied purposes, if there were just plain more computer power available.

JE: You're allotted time and that of course is a function of the number of jobs.

CP: That's right and if Pittsburgh had another C-90 and we could get it twice as often we could move twice as fast, that's the limiting factor at the moment in this work. It hasn't always been true. Sometimes we were stuck. But at the moment we know exactly what we want to do and we're one hundred percent limited by the computer power available.

DM: And it's not from lack of work that wants to be done, if they had a second C-90 that second C-90 would be busy. Just like the one they have now is. I believe they're turning people away because there are only so many resources to be allocated.

CP: It's a selfish thing to say but from the point of view of our work it's important for the government to invest in high-end best available computers. In so far that this work is important to do it can't be done without that and it could be done better if they did more of that.

JE: A lot of us hope that once the SSC, when there might be an injection of money that would do this kind of, my arguing the SSC is just that it's slopping up all the money and you guys don't have a prayer of ever seeing any in Pittsburgh where as I thought maybe with the SSC maybe it will happen, I don't know.

CP: I don't know enough about how those things work to know whether that would be true or not. But whatever the reason I hope the computer power up here is...

DM: Even dead the SSC continues to suck up money.

JE: Yes, I suppose it does, I hope it sucks up less than when it was alive. We got a section of it as you may know which we just put into the science show which just opened up last Wednesday and it's beautiful work, I'll say that. They do nice work down there. They didn't have anything else to do with it so I said send it up to us. They were going to include a section on the SSC in the exhibit but of course it all had to be rewritten. Well thank you very much, that's absolutely terrific, I appreciate your time.