Distributed Artificial Intelligence in Space

featuring James Edmonson as Interviewed by Suzanne Miller

Suzanne Miller: Welcome to the SEI Podcast Series, a production of the Carnegie Mellon University Software Engineering Institute. The SEI is a federally funded research and development center operated by Carnegie Mellon University and sponsored by the U.S. Department of Defense. Today's podcast is available on the SEI website at www.sei.cmu.eRdu/podcasts.

My name is Suzanne Miller. I am a principal researcher here at the SEI. Today, I am very pleased to introduce to you to James Edmondson, a frequent guest on our show. Today, he is here to talk about distributed robotics in space. We have talked about other aspects of distributed dynamics: boats, other things, but today we are going to talk about it in space.

I am very excited about this since I worked in that arena for a long time. Before we get started on that, remind us a little bit, for those who have not visited with us before, about what your background is and what brought you to this kind of research.

James Edmondson: Absolutely. My name is Dr. James Edmondson. I work at Carnegie Mellon Software Engineering Institute. I work in a department called the Software Solutions Division. We focus a lot on cyber-physical systems and ultra-large-scale systems. A lot of what I do is really focused on middleware and verification of distributed systems, generally in hostile environments: things that are not going to cooperate with you. They are not internet connected, and they are certainly not highly connected. They are not always available.

My chief interest is in pursuing artificial intelligence and distributed artificial intelligence or just distributed autonomous systems. You can think of them as a range of gradients. I am not talking about self-aware AI [artificial intelligence]. I am talking about a mission-focused artificial intelligence you created just to complement what you, as a human being, would like to accomplish. So, that is my focus area.

Suzanne: It is adding sensor capability, adding information to the decision-making process that is needed in conflict situations.

James: Usually it is about increasing your reach as a person, as an operator, making you able to do more things at once.

Suzanne: Let us talk about--you call them *smart tiles*. These are components that are meant to be launched into space and collaborate for power and other kinds of missions about collecting power, emanating power, really to support very long-term kinds of mission capabilities that NASA and others are thinking about but really have a lot of barriers to actually being able to achieve. One of them being, *I am out in this hostile environment, and I have limited power, and I have limited space to actually work in*.

Tell us how this idea came about, and where are you with it?

James: We started in a place called the Keck Institute for Space Studies. It is a part of Cal Tech, California Tech. It is really a very close coupling with the Jet Propulsion Laboratory [JPL] there. They are really focused on NASA problems. They are really focused on space and a lot of environmental concerns and trying to figure out what the 10- to 20-year vision for NASA will be as far as exploration of the solar system.

We were in in a workshop series called "Adaptive Multifunctional Space Systems for Microclimate Control." It was really talking about some very exotic things like, for instance, *What can we do on Venus?* Because Venus has a sulfuric atmosphere. It corrodes everything we put in it. How would we harness energy there? We were talking about some very exotic things, about using the winds and various upper atmosphere and things of that nature.

Another topic came up when we were talking with Jean-Pierre Fleurial and Karl Mitchell, who are energy experts at JPL. They were talking about renewables, where you could use thermoelectric gradients. Thermoelectric gradients are temperature differentials, which can create electricity just from having a hot surface and a cold surface.

But what Jean-Pierre was talking about was something a little more interesting, that you could create them off of very low gradients. So, if you just put something on the surface of a planet and you dug a small hole in there, the bottom of the pit where you dug the hole and the top of it, where hopefully it is getting sunlight or something, have enough temperature differential to give you small amounts of electricity. If you are in remote areas like this, that could be enough to power important things for indefinite periods.

It kind of built into this thing. We started talking about, *What would we do next and how would we make this better?* The smart tile kind of naturally evolved out of that. I should mention that there are several collaborators on this. I do not want to seem like I am the only person working on this.

The brainchild of this, and the workshop series, was Marco Quadrelli from JPL. James Lyke from AFRL Space Vehicles is also in there. Then you had people like Christos Christodoulou, who is at the University of New Mexico, who is working on an important part of this called electromagnetic antennas, which are able to beam, for instance, usually it is signals. One of the things that was really weird that we talked about here was beaming power.

We started talking about, basically, *What if we were to make millions of tiles? We make millions of power-gathering with solar kind of power but also thermoelectric gradients that were able to harvest just from ambient temperature? And you could make these work not only in sunlight, but you could have them on a dark side of the planet or, whatever--as long as there is temperature differential.*

It could be from you seeding heat. For instance, you come from a hot part of the solar system. You are warm. You have electronics that are working. You go into the cold part. Just the heat that you already have in there, the availability of the temperature differential that you will have from the cold surface to this, would be able to give you electricity for a certain period of time. As long as you have a deep enough battery.

We were talking about that. Then we started talking about the beaming part of this. And JPL had some interesting things about beaming across distances. You lose 60 percent of the power that you might have gained. But if it is an indefinite renewable energy resource …

Suzanne Miller: It is like a trickle charge.

James: It is perpetual. Yes, you lose 60 percent in energy, but you still have a capability that was not even there before. It is infinitely useful. That kind of branched into this other thing. What happened was I kind of came up with the distributed smart tile idea. We started talking about it, and I started writing the chapter that came in the JPL report.

There are a lot of software problems that we had been thinking about at the SEI for decades, about this. One of them is right here in this *Ultra-Large-Scale Systems* book. This is a long-forgotten tome here at the SEI, written back in June 2006. At least that is when it was released.

Suzanne: 2006.

James: Linda Northrop and various other people, Kurt Wallnau, a lot of other people worked on this. A lot of the problems that you see in this book about emergent behaviors, about designing reliable systems and things of that nature in these kind of environments—and this was just about Internet, mostly. It was not even talking about space, where it is a lot worse conditions—but a lot of problems that you see in here are things we have been working on for the last 10 years in anticipation of these kind of systems evolving. It has been exciting to work on something that you see these correlations directly.

Suzanne: Absolutely. So where are you right now? Where is this? Where are we in the software problem space with this?

James: The nice thing about a lot of the work I do is that it is portable to many things. So the MADARA and GAMS middleware that I have been working on for a while—that is Multi-Agent Distributed Adaptive Resource Allocation--just call it MADARA—that has been around for a while. It is really about distributed knowledge sharing amongst these autonomous systems in unreliable environments where you have to resend information, where you do not expect things to arrive all the time.

Then GAMS, the Group Autonomy for Mobile Systems project, was really about making things autonomous and able to collaborate together. It turns out that these software are pretty ready made for inclusion in this. We have already been running a benchmark test in vacuum chambers and other places to see how this runs on a Raspberry Pi and the kind of form profile that we are going to have on the smart tile.

We have already created a lot of the hardware prototypes that we think we are going to put up either later this year, this coming year in 2017, or in 2018. It just depends on when we feel like we are ready to put this in there. What we are going to be doing is putting six of these up in orbit, low Earth orbit, for about a year. So we do not want to mess things up right now and have something that just does not work for a year. We want to make sure that we have everything designed well. And this is kind of a fruit of love.

This is a lot of people just coming together working on this: Howard Bloom, James Lyke, Marco Quadrelli, Christos. You have got John Valasek, a lot of other people that come into these telecoms every two weeks. A lot of these are working in the labs at GE Global Research: Glenn Forman and Kelvin Ma. They are in it every day.

The progress can seem a little slow when you are in these kinds of processes and seeing parts fail and getting the correct part in there and doing it iteratively. We are looking at a first prototype in low Earth orbit of about six tiles collaborating, sharing information.

I am not sure if we will be sharing power yet because this is just a first stage to see if the software layers work. It is really testing out the SEI part of this, of whether or not we can collaborate, whether or not we can do this in space for a year, essentially.

Suzanne: We can simulate some aspects of space. We can do vacuum testing. We can do very low-temperature kinds of things. We can do some of the radiation hardening testing, but bringing that all together really is an on-launch kind of thing.

This is what you are trying to do, is make sure everything will—before we do add function—make sure that the basic communication, the basic safety, do not run into other things that are up there. There is a lot of space garbage. That is really what that test is going to be about, just really getting that platform to be stable. Is that correct?

James: Hopefully we won't run into too much garbage. Right now, our tiles, they are very low weight, so in general they would bounce off something like that unless it is coming in like a bullet.

For the most part what we are doing now, GE's Global Research Center has put up a lot of space vehicles and, along with AFRL Space Vehicles Branch, they are really bringing their expertise to bear on a lot of that. We are at a level of low-earth orbit where it is not like in conflict with the International Space Station or that kind of stuff. It is really at a lower orbit. We do not think we are going to have to deal with so much of that.

A lot of what we are going to be focusing on is the collaborative nature of the tile and really thinking of basic experimentation in space. I fought to have a propulsion system in there, but what we are mostly going to have right now is the ability to rotate the tiles so that it faces the sun at all times. That is really the only locomotion I have available, but it is something I can program. As part of the smart tiles autonomy, it is going to be doing that kind of automation and adjusting itself.

There are also simple things like voting and options for leadership in this, the tiles, whose going to talk to Earth because each of them are equipped with an Iridium chip set that can communicate back with Earth. Iridium is very expensive. You really do not want all of them chatting all the time about the silliest things that they have, *What my temperature is* and various other things.

Really what we are going to design it for is to have one of them talk to Earth. If one of them fails, they essentially will vote on who is going to be the next leader. That person will be the kind of proxy for everyone to talk between Earth and the tiles.

We expect there probably will be some failures. That's kind of the genius of the smart tile, is that if you put up millions of these and 33 percent of them die, you still have hundreds of thousands, if not millions, of other tiles that can communicate. They can do a lot of tasks, like localization for other people going places. I think one of the more interesting things that we have been talking about with potential customers has been power beaming, because it is not just something that affects space.

If you look at India, for instance. India has a lot of remote locations in it that have no power grid. If you were able to beam energy down to the surface of the Earth and lose 60 to 70 percent of it as you get there—maybe even 80 percent of it—but it is more energy than they have ever had. This could be something that could revitalize populations. It could help build infrastructure, because building the infrastructure on the ground is very expensive. But if you could service it from space, essentially, then we think that shows a lot of the power.

Another place we have been talking to is that satellites themselves need power. One of the things you have to understand about any kind of energy source in space is you cannot just send humans to fix it, so it just degrades over time. It gets worse. Over time you could go from 100 percent capacity to 20 percent capacity. What you do 10 years after you have been launched, or even 5 years after you launch, could be very minimal compared to what you had initially.

There are some people, and some companies, out there that are looking to license people to basically provide them with energy. If you have an energy-beaming thing, you don't lose as much beaming across space. You do lose a lot beaming through the atmosphere. That is a better client, really, if you want throughput in energy capacity.

I think that is the one that shows the obvious commercial viability of something like that. That is why GE's Global Research Center has been interested because they deal with energy. They would love to have a power infrastructure for the solar system. So, that is why they have been doing so much work on it.

We are always looking for more partners. We have had people come and go out of the group. I think after it gets in space, I will have a lot more interest in people coming because once they see it is real.

I mean, if you read the chapter in the JPL report, there were a lot of things that I wanted to do about environmental outreach and various other things where getting high schools involved in various other things where they could essentially talk to the tiles, ask them what they are doing.

Or, if we have locomotion, make them do something in space, like form a shape or something. These are all things that we would love to do; it is just not going to be in the first prototype we put out there. It is just the first step. It is definitely meant to be a 10-year project, not a couple of months and then we are done. No. It is something that will hopefully go on for a long time.

Suzanne: Speaking of prototypes, we have talked a little bit offline about the fact that we may actually be able to see one of these prototypes coming up in the future. I wanted to talk a little bit about what would we be able to see once we have a prototype in front of us? What kinds of things would we be able to do with that prototype?

James: We are going to have a full Raspberry Pi on it. There is a lot of computational power on each tile. You could really do a clustered application of various things. We have been talking about environmental sensing projects and other things of that nature for low-earth orbit.

What we would have in our hands is we have a prototype that essentially unfolds from a CubeSat volume into six tiles. So it is going to look like a box, but it has these latches and various things that will come apart in space. They will float away. Once we have a prototype that has the propulsion system in them, the ion thrusters, or even a packet of air—we talk about a condensed packet of air that you can puncture in six different layers—but again, they told me *Just focus on the first part of the project.*

Essentially you will see something with a computational layer, the Raspberry Pi. You will see photovoltaics on one side. And then you will see a battery, the lithium ion battery that will be storing energy. You will be able to hopefully hold that.

The prototype I have in my office right now is just showing the latching mechanisms and how it unfolds. You do not see the computational layer, or the photovoltaics now. But the one at GE that they have, that they have provided a picture [of] to me of, does have the photovoltaics layer, and it has been chromized and everything. And it looks really nice...

Suzanne: So, this is something for our viewers to look forward to.

James: Hopefully so, yes.

Suzanne: We are planning on doing a little bit of a demonstration of this once we get it available. This is very exciting. I am a NASA geek from way back. Some of these kinds of ideas are things that, you know, when you have watched the NASA Channel you see all kinds of animation of things that are possible. This is really coming to fruition, lots of different ideas. I am really looking forward to being able to touch the prototype and see some simulations of its functionality.

I want the thank you very much for joining us today, James.

James: Thank you.

Suzanne: This is wonderful stuff. I do want to mention to our viewers that the link to the Keck Institute report that has the chapter on the smart tiles will be available on transcript for the podcast. And you have got another blog post related to different aspects of this, and it will also be up there.

Today's podcast, as always, is going to be at sei.cmu.edu/podcasts. And look under James Edmondson, and you will find lots of interesting things, not just this. I think we will also make sure there is a link to the ultra-large-scale systems report. I agree with you, James, that this report was amazing at the time, the kind of thinking that was going on. And it was very-- I think very much ahead of its time in terms of the ideas; and now some of them are, we are actually starting to be able to use. I think that is wonderful.

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