"LIFE'S LITTLE QUESTIONS"
SHOW 904

Episode Open
Why Are Peppers Hot?
Can You Beat Jet Lag?
How Do Bees Fly?
Why Does Traffic Jam?
Sand to Nuts

EPISODE OPEN

ALAN ALDA: Just a few minutes ago I was cruising down this highway with nothing in front of me, and now look. Did you ever wonder how traffic jams materialize out of nowhere like this?

ALAN ALDA: (Narration) Or did you ever wonder why peppers taste hot?

ALAN ALDA: Smooth

ALAN ALDA: (Narration) Don't you wish you could beat jet lag -- even if it means lighting up your legs? Have you noticed bees can fly -- though science still doesn't quite know how?

ALAN ALDA: You really do love sand…

ALAN ALDA: (Narration) And what makes sand so much fun?

ALAN ALDA: I'm Alan Alda. Join me now as Scientific American Frontiers attempts to answer some of Life's Little Questions.

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WHY ARE PEPPERS HOT?

ALAN ALDA: (Narration) It's good to know that scientists are trying to solve the really big mysteries of life. How did life begin? When will the universe end? Will we ever make a robot that's smarter than we are?

ALAN ALDA: Now we like big questions as much as the next science show. But this time, we've set our sights firmly on the trivial - on the fascinating little questions that crop up in everyday life. Except we got a surprise - which makes us wonder if there are any truly trivial questions in science. Because, as we quickly discovered, one thing keeps leading to another.

ALAN ALDA: (Narration) Take the first question we asked. It's why we're here in Santa Fe, New Mexico, at a food festival that celebrates what's practically the state food - the chile pepper. The question is of great personal interest to me. But it isn't one you'd imagine leading to a medical breakthrough.

ALAN ALDA: So here's the question: Why are peppers hot? Well, why are they hot?

PAUL BOSLAND: Chiles are hot because they have a compound, or a set of compounds, called capsaicinoids that's found inside the fruit, along the placenta. And contrary to a lot of beliefs, the walls have no heat, the seeds don't have any heat, they're only in this one little area here - where this orange coloring is? - that is the capsaicinoids. So the more orange, the hotter the chile. We think in nature, the plant evolved this to keep mammals from eating the fruit, because when the seeds pass through a mammal's digestive tract, they're destroyed. And so - but birds can come along, pick the fruit off, eat it and then spread the seeds and put like a fertilizer pellet with it.

ALAN ALDA: So the capsaicin in pepper, which taste so hot to us and taste so good to me, is really to keep me from eating it, uh?

PAUL BOSLAND: Exactly.

ALAN ALDA: It's to keep mammals away and get birds to concentrate on them, because that's how the seed spreads?

PAUL BOSLAND: Exactly. The birds don't taste capsaicinoids; they don't sense the heat. What they're doing is getting a very good source of vitamin A.

DAVE DEWITT: The flavors and the aromas are why the world's cuisine have gone to chile peppers. In other words, within a hundred years after Columbus brought back the first chile pepper seed from the New World, they spread to the Old World, and completely went around the world in less than a hundred years, and what would curries be without chile peppers, what would Thai food be like without chile peppers?

ALAN ALDA: I know, I think of Schezuan food, one of my favorite foods, I can't imagine it without chile peppers, but they ate there without chile peppers for thousands of years I guess.

DAVE DEWITT: Thousands of years.

ALAN ALDA: (Narration) My hosts' plan is for me to sample some of the different peppers here so that I can appreciate their subtleties. But for me subtlety and peppers don't mix. So offered a choice of mild, medium or hot…

ALAN ALDA: Let's get hot right away.

DAVE DEWITT: OK, this is the Capsicum picatum, I'll let you try this. Also know as aji in South America.

ALAN ALDA: It's good.

DAVE DEWITT: Now you said you liked hot peppers.

ALAN ALDA: Yes I do.

ALAN ALDA: (Narration) I'm not the only one here playing with fire.

ALAN ALDA: When somebody eats a pepper that's too hot for them, what do you recommend to calm down their mouth?

DAVE DEWITT: Well there's a lot of folk remedies. People say if you eat sugar, or if you drink a lot of beer you won't care how hot it is. But mostly it's dairy products that help you, and the thicker, the heavier the dairy product the better. Like yogurt for example is good, sour cream is very, very good, and that's one of the reasons sour cream is served with enchiladas out here in New Mexico for the people who get burned out.

PAUL BOSLAND: We're gonna make you into a connoisseur…

ALAN ALDA: (Narration) Paul and Dave are still determined to teach me the fine art of pepper tasting. But I get the horrible feeling it's already too late.

PAUL BOSLAND: The three areas to look for is the front of the mouth, mid mouth and the back of the throat, the throat area.

ALAN ALDA: Tastes like oatmeal. I don't taste anything.

DAVE DEWITT: Oh, we burned your taste buds with the hot one…

PAUL BOSLAND: Well let's try this one. We'll see what happens here. It's a little hotter now.

ALAN ALDA: OK…Tomato sauce.

PAUL BOSLAND: Aargh!

DAVE DEWITT: We burned you out, that's what the problem is. It may be several hours before your palate gets back to normal.

ALAN ALDA: Why are we in red light like this?

ALAN ALDA: (Narration) Burned out my palate? This sounds serious -- which is why I find myself sitting in a very strange room in Baltimore.

ALAN ALDA: This is very futuristic.

SYLVIA KING: Yes it is.

ALAN ALDA: Oh look, there are little screens down there.

ALAN ALDA: (Narration) I've come here to check my heat-sensing abilities against some of the best-trained tongues in the world, belonging to the members of the pepper-tasting panel at one of the nation's largest spice companies, McCormicks. Silvia King is in charge.

SYLVIA KING: Everybody get set, and go.

ALAN ALDA: (Narration) We start with what's reckoned to be a mild solution of the hot pepper chemical capsaicin. SYLVIA KING: Swallow.

ALAN ALDA: (Narration) We're instructed to assign it a five on a heat scale of zero to fifteen.

SYLVIA KING: So is everybody ready? Rinse with water and rinse with a cracker.

ALAN ALDA: (Narration) A cracker, hmm? What happened to the sour cream?

ALAN ALDA: Does the cracker really clear out the sensation of heat?

SYLVIA KING: It will help. Get ready for your strong reference.

ALAN ALDA: (Narration) The idea here is to tune our tongues to a standard set of heats -- concluding with a dose of capsaicin scoring a respectable 13 on the heat scale.

ALAN ALDA: Smooth!

ALAN ALDA: (Narration) OK, with our tongues now calibrated, it's time to see how we all rate a sample from a real hot pepper -- which is why, by the way, the light's red -- to disguise the sample's color, so it won't influence our score.

SYLVIA KING: Set and go.

ALAN ALDA: (Narration) I'll give it an 8. And my fellow tongues?

MARIANNE GILLETTE: I would give it about a 7.9

OTHER TASTERS: 7.5…about a 7…7.2…about a 7.6…

ALAN ALDA: (Narration) Well that's a relief. My tongue seems right in line with the experts'.

OTHER TASTERS: 7.5…7.8…7…about an 8.2.

ALAN ALDA: I'm sort of amazed that I even could taste anything in the mild one, you know. I was really afraid when I came in here you'd say this is the mild one and I'd say, no that's water!

ALAN ALDA: (Narration) Of course, the spice company didn't set up the heat-sensing panel just for my peace of mind. It's one of several ways they check the heat of all the peppers they buy, so that their customers don't get a nasty surprise once the pepper's ground into powder or flakes. Still, heartened that my tongue has survived years of hot pepper pummeling, I took it to a specialist.

ALAN ALDA: So if I can taste this as extremely bitter I'm a…

LINDA BARTOSHUK: A supertaster.

ALAN ALDA: I'm a supertaster. If I can't taste anything…if it tastes like a piece of paper…

LINDA BARTOSHUK: You're a non-taster.

ALAN ALDA: Oh boy.

LINDA BARTOSHUK: And if it's something in the middle, you're a medium taster. Be sure the paper gets really moistened with your saliva and moves all around so it covers your whole tongue. Are you tasting anything?

ALAN ALDA: It's bitter.

LINDA BARTOSHUK: Ah yes, yes. Authentic supertaster.

ALAN ALDA: It's really bitter.

LINDA BARTOSHUK: Oh oh, alright, I think now's the time to take it out.

ALAN ALDA: If I'm not a supertaster, I don't want to know. This is close enough.

ALAN ALDA: (Narration) Only one person in four is a supertaster…

ALAN ALDA: Blech!

LINDA BARTOSHUK: I can't share that experience with you because I'm a non-taster.

ALAN ALDA: (Narration) While another one in four, like Linda, doesn't taste the paper at all. The paper was only the beginning of my tongue check-up - next came blue food coloring.

LINDA BARTOSHUK: OK, swallow. Move your tongue in your mouth a couple of times and swallow a couple times, and that will distribute the dye. And then we'll have a look. Stick your tongue out. Oh, magnificent, the staining is absolutely perfect, I can see the pink fungiform papillae. Your tongue looks like it's tiled in fungiform papillae. You definitely look like a supertaster.

ALAN ALDA: I'm a supertaster.

ALAN ALDA: (Narration) The fungiform papillae are little sprouts on my tongue. Each one harbors a half-dozen or so taste buds, with nerve fibers connecting them to my brain. While some of these fibers convey the sense of taste, most of them don't sense taste at all, but pain. Which brings us back to hot peppers.

LINDA BARTOSHUK: You are feeling way more pain from eating a red pepper than I would, for example.

ALAN ALDA: Because I have more of these structures.

LINDA BARTOSHUK: That's right. You have way more pain fibers so you perceive way more pain.

ALAN ALDA: This is really weird because I eat far more red pepper on my food than anybody I know.

ALAN ALDA: (Narration) Now of course it may be that I just like pain more than most people. But there's another explanation, which goes back to that hot pepper I ate in Santa Fe. Because it not only knocked out my sense of taste. After the initial burn, it actually numbed the pain fibers that nestle around my taste buds.

ALAN ALDA: Now that this is cooled a little I put the pepper in?

ALAN ALDA: (Narration) Which is why I'm helping make hot pepper candy. A dash of cayenne pepper before the traditional taffy pull…

ALAN ALDA: Both thumbs, I have both thumbs in the taffy. I can't get my thumbs out of the taffy.

ALAN ALDA: (Narration) And the result is a candy that Linda Bartoshuk uses to treat patients with painful mouth sores. The candy was the idea of a student of hers, but others had thought of it before.

LINDA BARTOSHUK: If you go back and read accounts of Aztec medicine, you'll find out that the Aztecs were using chile peppers mixed with honey to treat sores in the mouth. My guess is that every culture that has ever consumed these chile peppers has figured out that they are really good analgesics. We're just the last in a long line of people who've looked at that.

ALAN ALDA: (Narration) One man who's that happy researchers are again exploring the pain-killing properties of peppers is a long-term survivor of AIDS, living in San Francisco. A few years ago, he began suffering agonizing pain in his feet due to a condition known as neuropathy.

GEPPETTO: The pain was very, very deep inside my feet, just underneath the toes. The best way I can describe it was that there was broken glass in there, on the nerves, to the point my life was just becoming very sedentary.

ALAN ALDA: (Narration) An active runner and volunteer with the AIDS quilt project,

GEPPETTO: Apodaca became housebound, his pain controllable only with powerful drugs.

GEPPETTO: I thought that if this pain continues, and if all they can do for me is tranquilizers, then I just didn't want to go on any further. And that's pretty much where I was until I met the pain management crew and Wendye Robbins .

WENDYE ROBBINS: An interesting day to be doing this from a symbolic perspective. This is the start of the Jewish calendar.

ALAN ALDA: (Narration) Wendye Robbins, an anesthesiologist, figured if hot peppers numb pain in the mouth, why not elsewhere?

WENDYE ROBBINS: That was part of the originality of the invention, was realizing that the same nerve fibers that are present in the mouth and signal hot or spice when we eat them are also present on the foot and therefore can probably be interacted with in the same way.

ALAN ALDA: (Narration) Geppetto's treatment begins with a powerful local anesthetic smeared on his feet.

WENDYE ROBBINS: Before we put capsaicin on him we have to make sure he's pretty numb. Otherwise the capsaicin itself would be exquisitely painful.

ALAN ALDA: (Narration) The mask protects against the fumes from the capsaicin cream.

WENDYE ROBBINS: This is a hundred fold more potent than the stuff that's available commercially. This is 7.5% by weight. If I was to touch this to your foot, or to the foot of anyone else who wasn't anesthetized, it would be excruciatingly painful.

ALAN ALDA: (Narration) While we wait for Geppetto's feet to bake, we've time for a quick visit with another team of San Francisco scientists. With research materials bought from local supermarkets, their goal was to find the molecule in our bodies that responds to peppers' heat. Among the peppers David Julius and Michael Caterina tested was the habanero, the hottest of all.

DAVID JULIUS: Very pungent. Tearing my eyes. Making it a little hard to breathe. All for science, you know.

ALAN ALDA: (Narration) What the researchers have found is the molecule in our nerves that hot peppers activate when they cause their painful burn. The molecule sits like a trapdoor on the surface of the pain fiber. Capsaicin unlatches the door, allowing calcium ions to rush in -- and so firing off the pain message to the brain. Here's what happens when capsaicin is added to living cells that are cued to light up when the trapdoor opens.

MICHAEL CATERINA: If you were to take the neurons that normally respond to pain in our bodies and subject them to this same sort of assay, this is exactly what they would look like. They would start off purple and then when you added capsaicin to them, they would all light up. A silent scream.

ALAN ALDA: (Narration) The researchers discovered that very hot water also makes cells give this same response. In fact, the original job of the trapdoor molecule in our bodies may have been to detect and warn of dangerous heat. So here's the ultimate reason peppers are hot - capsaicin fools our cells into thinking they're on fire! Right now Geppetto's feet know the feeling only too well.

GEPPETTO: I'm beginning to feel a very, very, very hot sensation on my feet right now.

ALAN ALDA: (Narration) But just as the hot pepper candy relieves mouth sores, so Geppetto's much more dramatic treatment should relieve his much more devastating pain - once the burn wears off.

GEPPETTO: The first time we did it, my initial feeling when I got home was that the pain was so bad from the capsaicin that I couldn't realize that it was going to get any better. And as the third day came around and I was able to put on shoes comfortably for the first time, it was like being born again.

ALAN ALDA: (Narration) This time

GEPPETTO: was running again within the week - and if his previous treatments are a guide, he'll remain virtually pain-free for months. Meanwhile, Wendye Robbins hopes that many other patients with debilitating pain can also be treated with pepper's chemical heat. You see what I mean? One thing in science just seems to keep leading to another.

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CAN YOU BEAT JET LAG?

ALAN ALDA: One thing we do a lot on this show is fly across time zones. A two or three hour time change isn't so bad. But a flight to Europe or Asia or Africa can wreck me. So here's our next question - and I'm really interested in this one! Is there a simple way to beat jet lag? It turns out there might be. And the solution involves light.

ALAN ALDA: (Narration) Now of course, on this show nothing's ever easy. These wires, for instance, are to check that I stay awake during what has to be one of the weirdest experiments the Frontiers producers have ever talked me into.

ALAN ALDA: So what do you do, if you see me falling asleep, you come in and give me a nudge, or what?

PATRICIA MURPHY: Yes, we do. We're also collecting during this time saliva samples, to measure the hormone melatonin…

ALAN ALDA: Saliva samples…

PATRICIA MURPHY: So we come in and bother you every half-hour anyway.

ALAN ALDA: (Narration) See - I knew there was going to be more to this than just getting wires on my head.

ALAN ALDA: I find out about his stuff in stages. We're going to do something having to do with light and sleep, and then I find out they want my body fluids.

PATRICIA MURPHY: We could have done it with blood or urine, but we chose saliva. These lights are used for the way we used to do photo therapy…

ALAN ALDA: (Narration) Now it's hard to imagine falling asleep in front of a bank of glaring lights- which is actually the reason for the experiment I'll be in. But lights like this can shift a person's internal clock.

SCOTT CAMPBELL: We've known since about 1980 that when light is shone in the eyes, then it resets the biological clock. It's just like taking your watch and pulling the stem out and twisting it. And it happens quickly, within 24 hours, probably much more quickly than that. And by resetting the biological clock you also set the timing of any number of physiological activities, one of which is sleep.

ALAN ALDA: (Narration) Your biological clock is a pinhead-sized cluster of cells deep in your brain. The conventional wisdom is that it's a signal from the eyes that resets the clock. Which means there was a problem for people who wanted their clocks changed.

ALAN ALDA: They didn't like sitting in front of bright lights?

PATRICIA MURPHY: Right, your behavior is constricted here, you have to sit and make sure you're getting the light to your eyes, so you can't look down and read or knit.

ALAN ALDA: (Narration) But what if the bright light didn't need to be in your eyes at all?

ALAN ALDA: This is interesting, this is a weird looking light, it seems green.

SCOTT CAMPBELL: It's a blue light they use for the treatment of neonatal jaundice.

ALAN ALDA: (Narration) So here I am having lights designed for newborn babies to lie on, wrapped around, of all things, the back of my knees.

ALAN ALDA: You know my knees look pretty cute, come to think of it…

SCOTT CAMPBELL: We're going to tilt you back and slide you under.

ALAN ALDA: I think I saw an ad for this on late-night TV.

ALAN ALDA: (Narration): The black drape and putting the light sources under the table is to make sure volunteers for the experiment don't know whether the lights are on or not.

PATRICIA MURPHY: For the next three hours, we to expose you to the light.

ALAN ALDA: (Narration): The extraordinary hypothesis Scott and Patty are testing is that light on the back of my knees will work as well as light in my eyes in resetting my biological clock. My job is simply to avoid falling asleep for the next three hours…

ALAN ALDA: Not so fast Louie.

ALAN ALDA: (Narration) Which is why they're showing me a movie.

PATRICIA MURPHY: OK, we're going to give you a tube in which we'll have you collect a saliva sample.

ALAN ALDA: Don't watch - this is personal. Here, I've filled this with some really great looking goo.

PATRICIA MURPHY: Thank you.

ALAN ALDA: (Narration) My saliva's used to measure the hormone melatonin, one of the things controlled by the biological clock. When Scott and Patty first did this experiment, they were astonished at the result.

SCOTT CAMPBELL: The outcome was that light to the backs of the knees had the same effect on the biological clock as light presented to the eyes. We were able to both reset the clock to a later time and to an earlier time depending on the time we gave the light.

ALAN ALDA: Now this business of putting it on the back of the knee, it doesn't have to be on the back of the knee to get this effect, does it?

PATRICIA MURPHY: No, we don't think so. We're not sure, but we don't think so. We were looking originally for a place to put the light that was far enough away from the eyes that we could control that factor. We wanted to make sure that light wasn't getting to the eyes. So we chose a place…

ALAN ALDA: So in other words to make sure that it's somehow through the skin and not through the eyes that you're having this effect.

PATRICIA MURPHY: Right. And also there's a theory that if there is some signal getting to the brain from a place other than the eyes, that it might be carried in blood.

ALAN ALDA: (Narration) And the back of the knee happens to be a place where lots of blood runs close to the surface. One explanation for the result is that blood is getting light's message from the skin to the brain as some sort of back-up system for the more direct route from the eyes.

SCOTT CAMPBELL: There's no question that in humans light in the eyes is the preferred evolutionary choice. But what our finding suggests is that there are possibly other ways to get that light to the clock.

ALAN ALDA: (Narration) The experiment hasn't yet been confirmed by other researchers. But if it's true, the discovery could help people like me who have trouble sleeping through the night. As Frontiers discovered a couple of years ago when we were trying to record my dreams, I often wake up in the middle of the night and find it hard to get back to sleep. Many people with this problem have biological clocks that give their "get ready to wake up" signal in the middle of the night. Light can push it later - but the best time for the light is right before the signal's given.

SCOTT CAMPBELL: Now the interesting thing is that giving light at that time means that we have to give light in the middle of the night to have the biggest bang for our buck, if you will. And it's impossible to sleep with light in your eyes - you know that. So one of the things that our finding may prove useful for is presenting light at a more appropriate time for resetting the clock during sleep.

ALAN ALDA: (Narration) And if you can reset the clock during sleep, then maybe one day light pads could help us fix the problem we started with -- jet lag. It could give us a whole new reason for the in-flight movie!

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HOW DO BEES FLY?

ALAN ALDA: I read somewhere once that aeronautical engineers had proved that bumblebees can't fly… Isn't that great? What that really proves I guess is that bees are smarter than engineers. But it also leaves us with another of life's little questions. How do bees fly?

ALAN ALDA: (Narration) These particular bumblebees are collecting pollen in the garden of Downing College at Cambridge University in England. And Charlie Ellington, a biologist rather than an engineer, also once confirmed they're doing what's apparently impossible. Poring over slow motion film of flying bumblebees, Charlie spent countless hours measuring the exact position of the wings at every beat.

CHARLIE ELLINGTON: The most mind-boggling tedious thing you can ever do in your life, is analyze these films frame by frame. And what we would find is typically that the bumblebee wouldn't even be able to get up off the ground, or if it was up in the air it would fall down to the ground. Their wings are too small and they beat too slowly for enough lift to be generated conventionally to keep them up in the air.

ALAN ALDA: (Narration) And bumblebees, it turns out, aren't alone in defying the conventional laws of flight. Most other insects do too, flying along happily on wings that just shouldn't be up to the job. But finding where the missing lift is coming from was impossible with insects as small as bees.

CHARLIE ELLINGTON: So we had to change over to a bigger insect that flaps its wings more slowly, and in fact we chose this one for that. It's a big hawkmoth, Manduca sexta, it has a wingspan about 10 centimeters, it beats its wings about 25 time a second, and it makes the experimental work so much easier. You can see what's happening around the wings. And what we saw was that the airflow came up, and as it hit the leading edge of the wing it spiraled and swirled off of it. Just like a whirlwind or tornado it's a low-pressure region and things get sucked into low pressure. In effect it's sucking the wing up like that and this is producing two or three times more lift on the wing.

ALAN ALDA: (Narration) It turns out that this swirl of air lifting the wing is something aeronautical engineers know only too well. In airplanes it causes something called delayed stall.

CHARLIE ELLINGTON: This is delayed stall over the main wing of the plane, like that. And that's exactly what's happening over the insect wings, where you're getting a flow swirling around the leading edge, generating lots of lift. But on a wing like this, that lift builds up and breaks away, and then it drops out of the air because there is no lift anymore.

ALAN ALDA: (Narration) So for a human-engineered wing this extra lift is strictly temporary - and can be dangerous. But for an insect…

CHARLIE ELLINGTON: The trick that the insect has is this large lift it has briefly, the insect can prolong.

ALAN ALDA: (Narration) Finding out how an insect keeps the extra lift meant taking another leap in scale.

CHARLIE ELLINGTON: This is the Flappper. It's a big mechanical model of an insect, based on the hawkmoth. It's got a one-meter wingspan instead of just ten centimeters, flaps its wing once every three seconds instead of 25 to 30 times a second.

ALAN ALDA: (Narration) Exquisitely engineered, the Flapper's computer-controlled motors and gears not only flap each wing but bend and flex it.

CHARLIE ELLINGTON: The wing has been designed so that when twisted at the base and tip, it changes shape in between in the same way that the real insect does.

ALAN ALDA: (Narration) Using smoke to see the airflow, Charlie confirmed the miniature tornado around the wing. But the smoke also revealed something else - the fact that the tornado is sucked along the wing from base to tip.

CHARLIE ELLINGTON: Because it moves out to the tip, it doesn't grow so large here that it breaks away and the wing stalls. Instead it gets sucked out and kept under control that way.

ALAN ALDA: (Narration) So the swirl of air stays stuck to the wing - along with the extra lift it provides.

CHARLIE ELLINGTON: So the smoke gives us a qualitative picture of what's happening, you can see where the air is flowing. But what we need to do now is measure it so we can study it more exactly. One way to do that is to have little particles floating around in the air that you can track. And that's what these are - little soap bubbles filled with helium to make them neutrally buoyant and also filled with smoke to make them white or at least gray.

ALAN ALDA: (Narration) And so now, with 19th century books on insects lining the walls of its home, the Flapper untiringly beats its wings amid a gentle blizzard of bubbles. Because the path of each bubble can be tracked in three dimensions, Charlie Ellington hopes they will reveal exactly how much extra lift the spiral of air provides - and so finally allow insects to fly -- officially. Also flapping its wings for science is a real insect -- a fruit fly -- housed in the laboratory of Michael Dickinson -- a confessed fly fanatic.

MICHAEL DICKINSON: I think flies can perform certain maneuvers that are just simply unsurpassed. And we take these for granted because they're so common. But consider a fly landing on a ceiling, or a hoverfly hovering with pinpoint accuracy over a daisy. These are extraordinary feats of locomotion.

ALAN ALDA: (Narration) To find out how flies perform their extraordinary feats, Michael starts by chilling fruit flies to anesthetize them, then tucks them into a little chamber under his microscope.

MICHAEL DICKINSON: I'm going to apply a little gentle suction to hold him down. The next step is to put a little tiny drop of this light-activated glue, just behind the head. And the secret is to put just the right amount.

ALAN ALDA: (Narration) The glue - activated by UV light - was developed for dentists, but work very nicely on fruit flies.

MICHAEL DICKINSON: So there you have a fly on a stick.

ALAN ALDA: (Narration) Stick and fly are slid into a little video theater, designed with a fly's view of the world in mind.

MICHAEL DICKINSON: I've just aligned the fly so that we can pick up its wing beats with a photosensor, and now I'm starting to engage the feedback so it can fly itself through a little virtual world, if you will.

ALAN ALDA: (Narration) The fly's wings can't move their owner, but they do control the movement of the vertical stripe. When the fly banks left, the stripe moves to the right, and vice versa. The V-shaped chevrons are under Michael's control.

MICHAEL DICKINSON: The chevrons are now moving down, and so the fly thinks that its moving upward. The chevrons are now moving up, and the fly thinks its moving down.

ALAN ALDA: (Narration) You can hear the fly's wingbeat change as it tries to dive or climb in response to thinking it's rising or falling. Right now the fly thinks its coming in for a landing as it's offered a tiny square of paper soaked in sugar water - an in-flight refueling stop. Michael Dickinson runs this fruit fly test pilot program to discover how they respond almost instantly to changes in their environment - not just what they see, but what they feel. Here the fly's being thrown around as it tries to steer for the stripe, and again you can hear the wingbeat change as it tries to keep flying straight and level. The fly's extraordinary skills depend crucially on what millions of years ago was another pair of wings. Called halteres, these dumb-bell-like structures have evolved from rear wings into gyroscopes, able to sense what's happening to the fly in the air, and providing almost instant feedback to the front wings so they can immediately respond. Studying this flight control system in detail takes a bigger fly - and this blowfly takes its test flights rigged with minute electrodes in its muscles. It's also given a metronome to fly toward and a flow of air to fly through.

CLARE BELINT: They don't like to be tethered, and it's a problem to get the animals to feel like their flying. All this complicated machinery is to get the animal to feel like it's free.

ALAN ALDA: (Narration) What you hear now are the blowfly's flight control muscles responding as it tries to steer toward the metronome, aided by its halteres, which are visible in slow-motion video. The lab is now focusing on how these gyroscopes work, enabling the fly to respond to hazards like a fly swatter in much less than the blink of an eye.

MICHAEL DICKINSON: I often go with members of the lab to see science fiction movies, especially about space aliens, which are extraordinary creatures fabricated in Hollywood. But I think all you have to do is go poke in a garbage can, and you're going to see animals that are much more extraordinary and fantastic than anything you're going to see in a Steven Spielberg film, and I'd rank flies as being right up there.

ALAN ALDA: (Narration) But for this fly, it's time for a rest.

CLARE BELINT: When it's ready to land, I give it back its world. Home sweet home.

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WHY DOES TRAFFIC JAM?

ALAN ALDA: (Narration) Most traffic jams come as no surprise.

JOE MORGAN: If you're northbound you've got some slowdowns on Route 24 and down here right below us on Route 95…

ALAN ALDA: (Narration) At rush hour, the sheer volume of traffic chokes up merges and intersections in patterns that are only too predictable and familiar.

JOE MORGAN: …expect some severe onramp congestion. Joe Morgan, 'BZ 'copter.

ALAN ALDA: (Narration) But then there's another sort of traffic jam.

ALAN ALDA: Just a few minutes ago I was cruising down this highway with nothing in front of me, and now look. Did you ever wonder how traffic jams materialize out of nowhere like this? Another one of life's little questions. It may seem strange that we're trying to find out about traffic jams on a road that's out here in the middle of nowhere. But as a matter of fact this road was put here because it leads to a very remote place.

ALAN ALDA: (Narration) The place is the Los Alamos National Laboratory, built here in the Jemez Mountains of New Mexico over 50 years ago to develop and build the atom bomb.

CHRIS BARRETT: Down over this way is a collection of houses that the senior scientists lived in, people like Robert Oppenheimer…

ALAN ALDA: (Narration) There are still a lot of scientists here at Los Alamos, but now much of their research is on less apocalyptic questions.

ALAN ALDA: We're driving down the road, and traffic slows down to a halt. And then it picks up again, and you look for what the problem was - there must be a wreck by the side of the road - and there's nothing. Where did it come from? And I know people wonder about this. I was telling my daughter we were going to talk about this, and I'm saying, you slow down and you look for the thing and there's nothing there, and she said, yes, yes, that's it, I always wonder that too. What's happening?

KAI NAGEL: Why didn't you bring her?

ALAN ALDA: She's already married. Tell me why it happens.

KAI NAGEL: OK…

ALAN ALDA: (Narration) Kai Nagel works on a project that simulates traffic in a computer.

KAI NAGEL: What we see here is a simulated freeway. And we see cars driving on that freeway. And what we see is a second-by-second snapshot of the situation, so this is why the cars are jumping.

ALAN ALDA: (Narration) Most of the time, the cars on this single lane highway go along just fine. But every now and then, when the traffic gets dense enough, one or two cars happen to slow down…

KAI NAGEL: Everybody slows down from time to time, sometimes it happens…

ALAN ALDA: When you get enough of that happening in the same space then you get a little knot of slowing down. So then what happens next?

KAI NAGEL: What happens here is we suddenly have someone who needs to slow down even more. What you eventually get is somebody who has to stop. And you see how the red knot keeps growing.

ALAN ALDA: New cars keep coming in, coming to a standstill, while other cars get out of the knot. But that knot seems to move back down the highway.

KAI NAGEL: Once you run into that jam, it can be totally disconnected from the original cause.

ALAN ALDA: Oh right, yes, so in other words, the original knot of traffic, the original jam, could have occurred by an exit ramp…

KAI NAGEL: Yes

ALAN ALDA: But then it propagates backwards, it maybe travels a mile back from the exit ramp, and I look out and I don't see anything, I see no reason, I don't see an exit ramp, I don't see an accident, I can't understand why I've just been stopped.

KAI NAGEL: Exactly.

ALAN ALDA: And it's because it started way up there, a mile up there.

KAI NAGEL: Yes.

ALAN ALDA: That's really interesting. Stuff happening that we experience someplace else.

ALAN ALDA: (Narration) But computer simulations today go far beyond answering why traffic jams appear out of nowhere. The Los Alamos labs' immensely powerful computers, built to simulate nuclear explosions, have recently been turned loose on simulating the traffic flow within entire cities.

CHRIS BARRETT: So TRANSIMS is a suite of simulations that simulates not just traffic, it simulates the populations, the roadway networks the populations are organized around, the individuals trying to move…

ALAN ALDA: (Narration) This for example is a simulation of a 25-square-mile section of Dallas. Every vehicle on the highway has its own destination, and has to deal not only with intersections and traffic lights, but also with every other virtual vehicle.

CHRIS BARRETT: So you find effects like this. There are lots of people that want apparently to get off at this place, and we have a jam backing up on the freeway and causing congestion, which will eventually break up but will build up to be pretty bad before it does.

ALAN ALDA: (Narration) The Dallas project is one step toward even more ambitious simulations - like one now underway to put the entire city of Portland, Oregon, into a computer. And not just Portland's system of roads and mass transit, but all of its people.

ALAN ALDA: That red part is where the people live, or where they're coming from?

CHRIS BARRETT: Exactly. We're going to go down and actually create synthetic households of individuals that correspond to the census in this region right here.

ALAN ALDA: (Narration) The Portland project is in fact creating hundreds of thousands of synthetic families, with every family member trying to figure out for him or herself how to get around the city in the course of their simulated lives.

CHRIS BARRETT: We can assign the guy a workplace and an activity list through the day that corresponds to what people of that kind in that block group do.

ALAN ALDA: And these are all his destinations during the day.

CHRIS BARRETT: During the day, this guy starts at home, goes to work, at lunch time he goes to lunch, goes back to work…

ALAN ALDA: So he has destinations and times to hit those destinations.

CHRIS BARRETT: Yes.

ALAN ALDA: (Narration) Once the daily schedule's been created, the computer turns it into travel plans. It's a mind-boggling notion - hundreds of thousands of synthetic people struggling away inside a supercomputer, trying to figure out how to get to work, to the doctor's office, the shopping mall; each having to cope with all the other simulated citizens going about their daily business. It's just like real life - and that, of course, is the whole point. TRANSIMS job is to provide city planners with an immensely powerful tool - for predicting the effect of a new traffic light all the way up to building a brand new highway. These little questions of ours just refuse to stay trivial.

CHRIS BARRETT: Mobility is an essential part of being a human. And certainly an essential part of how we impact our environment and how we interact with one other, every day.

ALAN ALDA: (Narration) In few cities is that more true than in Boston, where the Central Artery is a commuter's nightmare. But the elevated freeway is about to go underground, in one of the most expensive construction projects in history. I was met at Boston airport by project-wide engineer

SERGIU LUCHIAN:, whose job it is to make sure traffic flows smoothly once the new tunnels are completed.

SERGIU LUCHIAN: We're now going through the tunnel into the city of Boston. And the tunnel is fully equipped…

ALAN ALDA: (Narration) This is the Ted Williams tunnel, the first part of the project to be opened to traffic. It's equipped with cameras in the ceiling and detectors under the pavement to monitor traffic flow. The entire network of some 160 miles of new traffic lane, mostly underground, will be watched over from a control center that makes NASA's mission control look quaintly old-fashioned. Sitting here, operators can monitor every foot of the highway, and display what's happening on a huge video wall. Some 500 cameras can each be individually controlled, even zooming in close enough to read license plates.

ALAN ALDA: I'm going to be much more careful in tunnels from now on.

ALAN ALDA: (Narration) The project is so complex that it's been simulated on a computer at nearby MIT - a simulator that's constantly consulted by Sergiu and his colleagues.

ALAN ALDA: There, there, that's traffic coming up - those little dots are cars.

SERGIU LUCHIAN: Those are cars.

ALAN ALDA: But they're make-believe cars. They're virtual cars.

SERGIU LUCHIAN: They're virtual cars, but they are in full rush hour in the year 2004. And there are also different types of cars. You can see dual tractor-trailers over here, buses, trailers, private cars…

ALAN ALDA: Oh look, one says wash me!

SERGIU LUCHIAN: Exactly.

ALAN ALDA: There's a couple of lanes where they're moving slowly and right next to it are lanes where they're moving faster, and they're looking for ways to get in front of each other, aren't they?

SERGIU LUCHIAN: That's right.

ALAN ALDA: (Narration) In fact, the behavior of the simulated drivers is based on observations of the real thing. The MIT researchers videotaped hours of Boston drivers, and many of the vehicles in the simulations exhibit the same notorious habits. The MIT simulator has been especially useful in checking out the tactics the control center will adopt in the event that things go wrong.

ALAN ALDA: What's your worst nightmare here? I mean, this is all underground

SERGIU LUCHIAN: The worst thing that can happen is that on a hot day, if you want, an obstruction that will block one of the tunnels. This is where we simulated that stoppage, that block…

ALAN ALDA: (Narration) The plan is to close the tunnel entrance as soon as an accident is detected. Only when the block is cleared will traffic again be allowed to enter. The question was - how soon should the tunnel be reopened?

SERGIU LUCHIAN: The initial set-up was that the moment this was clear, they'd just turn that light green and everybody would just shoot down the tunnel at 50 miles per hour.

ALAN ALDA: (Narration) Letting in the traffic immediately - the most obvious strategy - turned out in the simulator to cause one of those backward waves we saw at Los Alamos. Cars had to screech to another stop - perhaps causing secondary accidents. So another strategy was tested -waiting until the traffic trapped behind the block starts to move before opening the tunnel entrance. Now the flow of traffic sweeping into the tunnel is smoother - and the ride faster.

ALAN ALDA: So making them wait until they have a freer flow gives them a shorter time in the tunnel than if you let them in as soon as the accident is cleared?

SERGIU LUCHIAN: That's what the simulator proved to us.

ALAN ALDA: And that's true in real life?

SERGIU LUCHIAN: That's true in real life as well.

ALAN ALDA: Wouldn't be so good if it was only true in the computer!

SERGIU LUCHIAN: That's right!

ALAN ALDA: (Narration) It's too bad though, that real life traffic jams can't yet be freed at the click of a mouse.

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SAND TO NUTS

ALAN ALDA: The beach is a great place for thinking up trivial questions. For instance, have you ever noticed that when you walk in wet sand, the color of the sand seems to change in a sort of halo around each footstep? Why is that? It's no coincidence that this particular little question popped up here, on the shore of Lake Michigan in Chicago, because at the University of Chicago are a couple of scientists who just love asking trivial questions about stuff like… well, stuff like sand. You really do love sand, eh?

SIDNEY NAGEL: Of course, it's one of the best substances there is.

ALAN ALDA: What about my question. Why do we get this sort of halo around our footsteps when you walk on wet sand?

SIDNEY NAGEL: What we've got here is sand in this squeeze bottle. And we've filled it with water to a little bit higher than the level of sand. And so, as I squeeze this, what's going to happen? Normally you would think that everything is just going to rise. But as you saw with the sand near the lake, you squeeze it and the water drops below the level of the sand.

ALAN ALDA: That's great. You let go of it and the sand goes down and you have a layer of water on top. You squeeze it - look at that water, it seems to go all the way down there and the sand goes right up

ALAN ALDA: (Narration) The explanation's actually simple. Squeezing the bottle makes the sand grains move past each other -- and to do that, they must first move slightly apart. The water then runs down into the bigger spaces between them. On the beach, my weight pushed the sand grains apart, and the water draining away created the haloes. In fact, whenever grains move, they must first move away from each other. For instance, only the seeds on the surface of this avalanche have the room to expand and so to flow. And it's when sand flows that it really gets interesting.

ALAN ALDA: What is this orange thing?

SIDNEY NAGEL: This is a puzzle, which has orange sand in this plastic tube, and in the middle of the sand we have this big steel ball. And the question I have for you is, the ball is on one side and I want you to get the ball over to the other side of the container.

ALAN ALDA: OK, so the ball is on this side, I have to get the ball to this side of the sand, eh?

SIDNEY NAGEL: That's the idea.

ALAN ALDA: OK, so the first thing obviously is to try to shake it.

ALAN ALDA: (Narration) Obvious perhaps -- but equally obviously, not effective. Stubbornly, the ball refuses to sink.

SIDNEY NAGEL: Suppose you try it upside down?

ALAN ALDA: It's climbing right up! There it is, there it is, it's right at the top. OK, what makes it climb up through the and like that?

HEINRICH JAEGER: Great question. And to answer that, we're going to the lab.

ALAN ALDA: (Narration) The lab we're heading for is the University of Chicago's Materials Center.

SIDNEY NAGEL: So this is the two dimensional version in a real laboratory situation of what you saw here.

HEINRICH JAEGER: Let's just turn this thing on.

ALAN ALDA: Look at that, wow! And there it goes, down the side. I was just going to say, I can see poppy seeds moving down here.

SIDNEY NAGEL: But this big one can't make it, can it?

ALAN ALDA: No.

ALAN ALDA: (Narration) The only thing going on here is that the container is being briskly shaken up and down. It's a fancy version of what can sometimes happen if you shake a can of mixed nuts. The shaking unmixes them, causing the large nuts to rise to the top. Remarkably, there's never been a good explanation for this phenomenon. But a clue came from that thin downward stream of grains I'd noticed along the wall. Here's what Sid and Heinrich think is happening. As the grains are thrown upward, those nearest the wall are dragged against it, slowing them down. When the grains fall, they're less densely packed, so there is less drag against the walls. The result: the grains next to the wall slowly move downward, setting up a sort of convection current. The current rises in the center, carrying everything with it. But at the walls the current is too narrow to take large objects down again, so they are left stranded at the top. In a shaken can of mixed nuts, the Brazil nuts present themselves ready for eating. All very interesting, but…

ALAN ALDA: Suppose mixed nuts is not the most important thing in your life. What else does this apply to, anything? Or is it great that we have this understanding of how particles move?

SIDNEY NAGEL: Mixing is a terribly important thing in the pharmaceutical industry. That is, if you are making pills out of various powders, you want to mix them. And if you don't mix them properly, then you'll have some pills that have all the binder and other pills that have all the good stuff, but having all the good stuff in one pill is very, very bad.

ALAN ALDA: You could kill somebody.

SIDNEY NAGEL: You could kill somebody with that.

ALAN ALDA: (Narration) A great example of how an apparently trivial question can lead to a very non-trivial answer. And how about this one? Why does an hourglass invariably contain sand?

ALAN ALDA: Would anything work in an hourglass? Could I put water in an hourglass and would I get the same timekeeping ability?

HEINRICH JAEGER: You could put water in an hourglass, of course.

ALAN ALDA: But it wouldn't do me any good…

HEINRICH JAEGER: It would not do the following. It would not be a linear keeper of time. In other words, what makes the sand here so remarkable is that no matter how high the filling height is here, the flow rate at the orifice is always the same. So if you have markings that tell you time - one minute, two minutes, three minutes, whatever - they are equally spaced. That has to do with the fact that most of the weight up here is unloaded not straight on to the hole, but it is going toward the side-wall.

ALAN ALDA: (Narration) The weight goes to the sides? Hard to believe - until Heinrich and Sid got my competitive juices flowing with a simple children's game.

ALAN ALDA: You've really got my interest now…

ALAN ALDA: (Narration): The curved bar - which is like gravity - pushes down on the wooden discs, representing grains. The trick is to remove the discs that aren't holding up the bar.

ALAN ALDA: This looks like it's free. Yeah. It's a big one. This looks like it's very much connected… but his doesn't look like it's connected. There, I got another one. I'm pretty good. Now this one I get for free. But it could be all the way down here. I'm guessing this doesn't connect to anything…

HEINRICH JAEGER: Beautiful.

ALAN ALDA: But this must…. Now, that was really a force against the side, wasn't it?

HEINRICH JAEGER: Correct. And so we started with a force coming down this way, but we ended up with a force against the walls. And the material diverted the force against the wall, and that's why the hourglass has this constant flow rate, because much of the forces from all the material above the orifice gets diverted against the walls.

ALAN ALDA: (Narration) One of Sid Nagel's favorite trivial questions confronted him one day from his kitchen counter.

ALAN ALDA: Are these historic coffee stains here? Are these the ones that gave you your inspiration?

SIDNEY NAGEL: Oh, they're a day old or so. But when they're as lovely as this, wouldn't you have trouble wiping them up?

ALAN ALDA: (Narration) Yes, it's true, Sid really does find coffee stains beautiful -- because they made him wonder why, when a coffee spill dries, it always leaves a ring. Enough of Sid's colleagues took the question seriously that experiments began to watch what happens as a coffee spill dries.

SIDNEY NAGEL: So Rob here has been looking under a microscope at some of the drops that instead of using coffee we've used particles that you can visualize under microscopes.

ALAN ALDA: I'm seeing a lot of particles moving from over here to the edge.

ALAN ALDA: (Narration) The question was, what's causing this flow? The answer hinged on the fact that the edge of a spill becomes pinned in place by tiny rough spots on the surface, so the edge can't pull back as the liquid evaporates. As the edge loses liquid to the air, it has to be replenished by liquid from within the drop - and the flow that results carries with it the tiny suspended particles.

ALAN ALDA: Is this white band particles that have built up on the edge already?

SIDNEY NAGEL: That's right. And so you see how slowly and carefully they come in there and they pack very nicely into a very well packed, almost crystalline ring.

ALAN ALDA: (Narration) The careful packing means that even this humble discovery could have unexpectedly useful consequences - for instance in manufacturing ultra-fine wires in electronic circuits. So even in coffee stains, there can be inspiration.

ALAN ALDA: It's really interesting to me that this kind of stain from a few drops of coffee has probably shown up on countless millions, thousands of millions, of counter tops…

SIDNEY NAGEL: On my counter top alone it's shown up that many times!

ALAN ALDA: And many of these counter tops were the counter tops of serious, curious scientists. And yet you and the people you work with took these stains seriously and you thought that something can be learned from that that will lead us to a deeper understanding of things other than coffee stains

SIDNEY NAGEL: I have this kind of broad view of what physics should be. And it's not just building the big new superconducting supercollider or a new Big Bang theory of the universe. It's also trying to understand phenomena such as this that gives us the feel and texture of our daily lives, and it's just important to understand.

ALAN ALDA: It's possible then that by studying things like coffee stains on the counter top and sand in an hourglass or nuts in a container of mixed nuts really can give you some insight into how the whole universe is formed.

ALAN ALDA: (Narration) Which, if you recall, is just where we came in…

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