The amazing food replicator

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"TEA. Earl Grey. Hot." If only astronauts on the International Space Station could summon their creature comforts as easily as Jean-Luc Picard on *Star Trek*'s starship Enterprise. After six months on the ISS, watching the sun rise 16 times a day, astronauts have eaten more than 500 tedious meals of dehydrated, long-life food. Who wouldn't give their right arm for a pizza bubbling with browned mozzarella or a fresh cream bun?

The wacky "food replicator" in Star Trek was pure make-believe. It stored 3D scans of the molecular structure of drinks and meals, then miraculously assembled individual molecules into these foods in seconds. That technology is way beyond our horizons, but a NASA-funded study is about to look into a simpler option - a compact cooking machine that will create a larderful of familiar foods from a limited range of space-friendly ingredients.

The idea is that you could request a sherry trifle, for instance, from a computer. That request would be translated into mathematical instructions controlling a food processor. A network of pipes and chambers would mix, heat and cool the ingredients to make a dessert that looks and tastes like a real trifle - even if it is made from unconventional ingredients.

Back on Earth, such machines could also invent foods to tickle the taste buds by "evolving" recipes. "That would be a completely new approach to food design," says Eric Bonabeau, chief scientist at Icosystem, a strategy research firm in Cambridge, Massachusetts. "I think this project could have great potential not just for space, but for the food industry as a whole."

Space food has come a long way since John Glenn squeezed apple sauce out of a tube during his pioneering three-orbit Project Mercury flight in 1962. But there is still plenty of room for improvement. Neither the space shuttle nor the ISS has a fridge or freezer, so the vast majority of food is not fresh. "The foods have to be able to last at ambient temperatures for fairly long lengths of time," says Vickie Kloeris, NASA's manager for shuttle and ISS food at the Johnson Space Center in Houston, Texas. "For the station, everything needs to have a 12-month shelf life."

Drinks are powdered, while most of the food is either freeze-dried or the equivalent of canned food that can be sealed in lightweight pouches and heated in an on-board microwave oven. Astronauts have about 300 items to choose from, and the menus repeat every 10 days. That is dreary enough on a six-month mission to the ISS, never mind future manned trips to Mars, which could take years. "On a Mars mission, the food could be 3 to 5 years old by the time the crew eats it," says Kloeris. "We have a few products which last that long, but not many. We couldn't yet provide sufficient nutrition and variety."

NASA is researching ways of extending the shelf life of food for a Mars mission, and ways of growing fresh food in space. But Bonabeau suggested something more ambitious to the agency's Institute for Advanced Concepts (NIAC). Why not turn fiction into reality, and design a food replicator?

The idea occurred to Bonabeau last year when he was talking to his friend Hervé This, a physical chemist and food specialist at the College of France in Paris. Along with the late University of Oxford physicist Nicholas Kurti, This developed the field of "molecular gastronomy", which aimed to give cookery a scientific framework and debunk culinary myths. He works with top Parisian chef Pierre Gagnaire to come up with an innovative cooking concept or recipe every month.

It is part of a wider trend for creating exotic new foods made famous by trendy restaurants such as El Bulli, north of Barcelona in Spain, and the Fat Duck in Berkshire, UK. At the Fat Duck, chef Heston Blumenthal serves up a 16-course tasting menu that you will never forget. First comes a green tea and lime mousse that the waiter rolls around in a frothing pail of liquid nitrogen until it's crisp. It collapses in your mouth as a fog of nitrogen puffs out your nose. Then comes a host of eccentric combinations that confuse and surprise the senses: snail porridge, caviar on white chocolate, bacon and egg ice cream.

In the course of his research over the past few years, This has started to develop a symbolic language to describe food (see "Mathematical recipes"). He and Bonabeau reckon that by extending this language to fully describe a recipe, then feeding the formulae into high-tech, automated food processors reminiscent of those in Roald Dahl's *Charlie and the Chocolate Factory*, it should be possible to generate millions of new and interesting foods without much manual labour.

Hoping that such a machine could open new avenues for space food, NIAC has given the green light to the project. With $75,000 in funding, a six-month feasibility study will begin in September. The first goal will be to create a mathematical "grammar" to describe a food completely, by developing This's textural descriptions to include details such as step-by-step cooking instructions. The grammar for a chicken pie, for instance, could include the instructions for mixing the dough ingredients, making a gravy separately, then bringing half-cooked pastry, gravy and chicken together for a final baking to deliver a steaming hot pie.

Next, Bonabeau and his Icosystem colleague Daphna Buchsbaum will use design software to create a virtual food machine. They hope to find the best networks of pipes and chambers, storage vats, ovens and fridges to execute the cooking instructions. A user might request food at a computer keyboard, and then a stack of five ingredients, say, could be processed up through a pyramid of nine different chambers that can perform 10 different functions - for instance, mix, whip, fold, decant, bake, grill, pressurise, quench, cool and freeze. That network would have 1 billion function configurations.

For extra flexibility, the chambers could be connected by closed pipes or open conveyors that themselves alter the food, perhaps by heating or chilling it. And loops could be added to repeat steps, such as whip, heat, cool and whip again. While Bonabeau and Buchsbaum work on possible designs, researchers at Squid Labs, an engineering company in California, will study the feasibility of building an actual machine. They will look at ways to overcome the mechanical hurdles, such as finding ways to clean and maintain the machine.

If it was on a space station the machine would have to be compact, perhaps the size of a domestic fridge. That means it would have to work with a small range of long-life ingredients, yet still make recognisable foods from them. Bonabeau hopes to identify the minimum basic ingredients, or food "phonemes", from which you can make decent replicas of many familiar foods. He has no idea yet what those ingredients would be.

Ideally, though, it would be possible to make a product that looks and tastes like puff pastry, for instance, but contains no fresh butter. That's going to require some ingenious thinking.

And work by Homaro Cantu, head chef at a Chicago restaurant called Moto, is helping to make this a reality. Cantu has devised some ingenious tricks, including making a Canon ink-jet printer dispense fruit and vegetable "inks" onto edible paper (*New Scientist*, 12 February 2005, p 23). He prints out sushi that looks and tastes like the real thing, but contains no fish or seaweed. Bonabeau hopes to pick up a few tips from him, though Cantu has not yet divulged the secrets of his techniques.

Bonabeau is not sure if it's possible to develop a useful food replicator. NIAC funds ambitious projects that few commercial organisations would contemplate, ideas that push the limits of science and technology but are unlikely to succeed within a decade. "These grants are for exciting technologies that are maybe 40 years in the future," Bonabeau says.

Taste exploration

But a food replicator could be a godsend not just to space travellers but to the food industry as well. The machines could turn up on street corners and aboard aircraft, or even dollop out lunch in school canteens - following strict nutritional guidelines, naturally. And a ground-based food-replicating machine could be large, complex and use any number of ingredients. It could invent all kinds of foods with textures and tastes never explored before.

The key lies in the mathematical descriptions. As well as using these to describe familiar foods, computers could use the language to generate hundreds of new ones. A chef could taste the food and select the best to be "cross-bred" and "mutated" to evolve improved edible "offspring" - just like Darwinian evolution. Cross-breeding might involve splicing the mathematical formula of one promising food onto another. Random mutations in the formulae that tweak ingredient amounts, mixing processes or cooking times would increase diversity.

"What's special about this kind of interactive evolution is that a human being plays God, deciding which 'creatures' will make it into the next generation," says Bonabeau. "You don't need to justify or qualify your decision: you can direct the evolution without ever having to express why you're selecting what you want."

The sheer number of foods involved in such an evolutionary process might pose a problem. "We want to create many generations, but there's a limit to how much food someone will want to taste," says Buchsbaum. She hopes to design intelligent software that can identify different food qualities. Then the machine could mathematically evolve several generations of new foods, making its own decisions about which food is "fittest". As it needs no verdict from the chef, it wouldn't even have to make the food.

Eventually, the machine could cook its new recipes and then seek the chef's approval. "I'm not convinced that this will replace the need for chefs and handmade food," says Buchsbaum. "But you're opening a new avenue for exploration."

Chef Blumenthal thinks the food replicator is a great idea, on paper. "If it was doable, it would be a fantastically exciting piece of kit," he says. He'd like to use it to test ways of engineering foods that dramatically change taste every few seconds as you chew them - a bit like Willy Wonka's three-course-meal chewing gum. "You could almost have a whole meal in one mouthful," says Blumenthal.

He would also love to use the machine to create experimental tastes and textures that tease out the deeper workings of our food psychology: "That's what really fascinates me," he says. "How much of flavour perception is related to the physiology of the food you eat and how much is a psychological thing?"

But Blumenthal suspects the machine won't be practical. Bonabeau agrees it's early days and there are still hundreds more questions to answer. How would you interact with the machine, for instance? Would it understand spoken requests, such as "Give me a cream cake", in multiple languages? And which foods would be subjected to Darwinian evolution first?

"To be honest, we haven't put much thought into these things yet," says Bonabeau. "It's all fun, but we're putting a lot of cart before the horse here." Still, he can't resist speculating. Perhaps the food replicator should not only understand speech, but even read your mind, he says. And as to the first food: "I think it would have to involve chocolate. Yes...it will be something to do with chocolate."

Sidebar –Mathematical recipes

DEFINING a food such as apple tart or beef stew in a mathematical language is a big challenge. The maths must encode all the food's features: the ingredients, how they are mixed, folded or layered, and all the steps in the cooking process. No one has ever invented a comprehensive mathematical language that can describe food in this way.

But Hervé This, a specialist in "molecular gastronomy" at the College of France in Paris, has made a start by inventing a symbolic language to describe food consistencies (see Diagram). The language uses symbols to represent different solids: D for dough and B for butter, for example. Other symbols describe how these ingredients interact with each other, the Greek letter , for instance, means "superposed".

Take puff pastry prepared according to a traditional French recipe. You would start with a layer of butter sandwiched between two layers of dough - DBD. You must then roll this out and fold it over twice to make (DBD)(DBD)(DBD), which can be written $D(BD)^3$, since two layers of dough that come into contact make one. The generic formula for puff pastry folded "n" times is then $D(BD)^{3n}$. Which means that after stretching and folding both ends the recommended six times, you end up with a staggering 729 layers of butter on dough, described by $D(BD)^{729}$.

Because dough is a dispersion of starch (S_1) granules inside a gluten (S_2) network, and butter is water dispersed in oil (W/O) dispersed in solid fat (S_3), the final formula for puff pastry becomes $(S_1/S_2)((W/O)/S_3)(S_1/S_2)^{729}$.

Complicated as the formulae seem, they are still fairly vague. They don't tell you the proportions of the ingredients, or how long you should cook them for. But researchers at Icosystem in Cambridge, Massachusetts, plan to extend the formulae to specify all these instructions. They hope that one day, a high-tech cooker could receive a request such as "bacon roll", translate it into the grammar of food, follow the mathematical instructions and deliver the finished article within seconds.