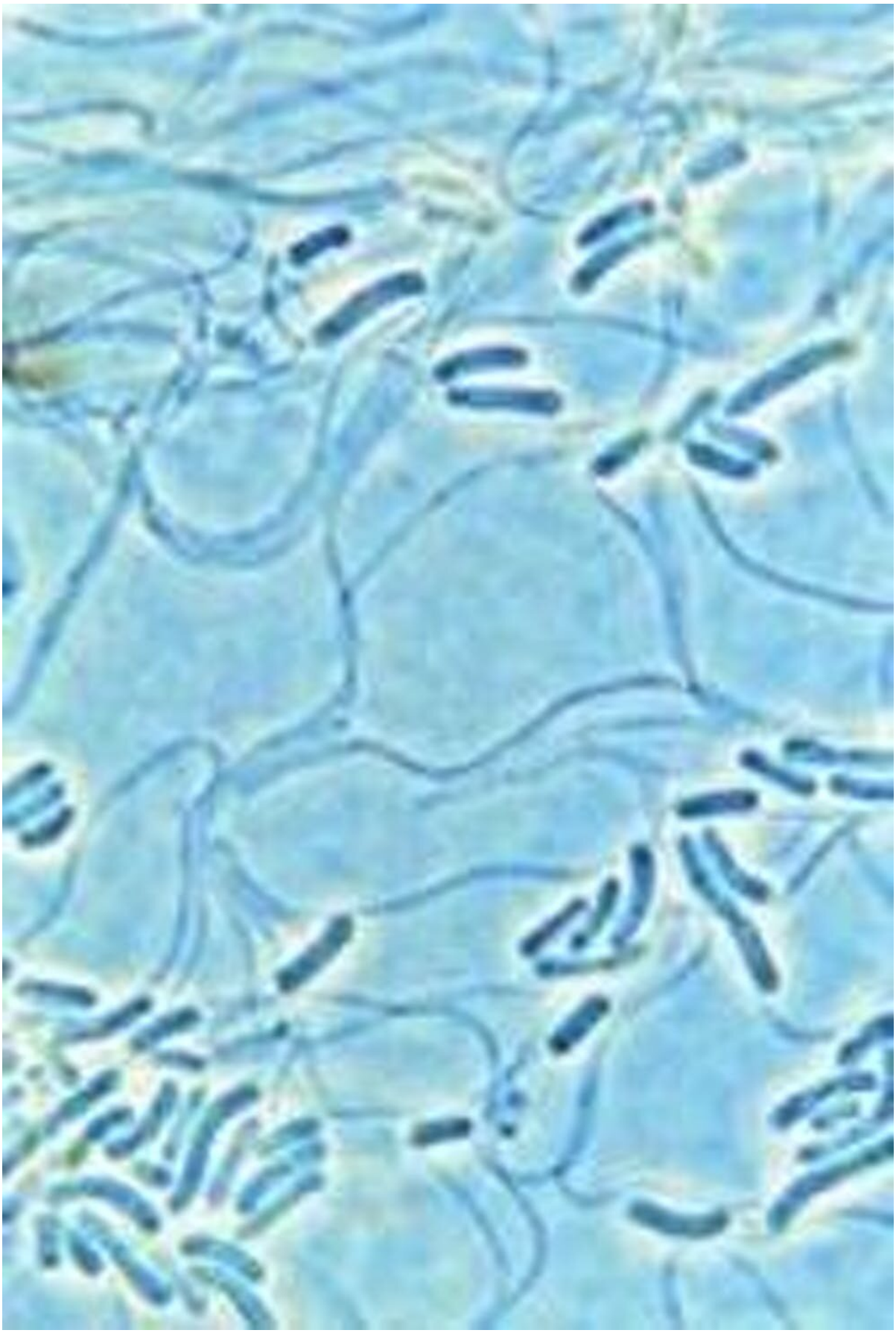
Microbes can produce food, fuel and medicine: Math can make them even more useful

July 29 2021, by Alex Dos Reis de Souza



Glycolate-excreting bacteria from the hotsprings of Yellowstone. Credit: Microbe Wiki

Humans have harnessed the power of microbes for centuries, for example using yeast to make bread, beer, yogurt and wine via fermentation. These living organisms are useful to us because they perform chemical reactions as part of their everyday life.

Today, we can use microbes to produce many valuable chemical compounds, such as biofuels (including methane and ethanol) and medical products (such as antibiotics). We can also use micro-organisms to recyle wastewater by eliminating dissolved organic matter.

Over the past two decades, scientists have investigated how humans can use new biological systems that do not occur in nature. For instance, bacteria can be genetically modified to act as "bio-sensors", and light up in the presence of certain compounds, such as oil or even pathogens.

We can also engineer species to work with other microbes, which could lead to entirely new biological systems with enhanced capabilities. Over the past 10 years, the use of these microbial consortia (or co-populations) have become more common. By associating different bio-engineered microbes with one another, the new community can perform different tasks and even outperform those possible with a single species.

For example, if one of the two species produces acetate (which is toxic) when consuming glucose to perform a certain task (such as production of a valuable compound), a second species bioengineered "to eat" the acetate could be introduced to detoxify the environment.

The two digesters at the Back River Wastewater Treatment Plant near Baltimore, Maryland. Anything that is solid and organic eventually ends up in these where it gets eaten by microbes and turned into methane. Credit: Kristian Bjornard, CC BY-SA

Controlling microbes with maths

These efforts have drawn the attention of not just biologists, but of computer and systems theorists, as well as mathematicians.

Advanced numerical techniques help us to understand and predict the behavior of biological systems, and there are many mathematical tools that allow us, for instance, to study the behavior of systems described by

a model, including their stability and response to external influences. In doing so, it is possible to enforce a desired behavior in the microbes and thus optimize the biological process.

Bacteria, for example, love glucose—the more glucose there is in their environment, the more they grow. Therefore, scientists can develop algorithms that tune the amount of glucose to adjust the concentration or the behavior of these bacteria, according to what biologists need. It is also possible to stimulate microbes using light or specific chemical compounds.

These tasks are not as simple as they may seem. Biological systems are inherently uncertain: many factors can alter the behavior of these systems, and they are not easily identified.

The mathematical models used to control biological systems can therefore be imprecise or fail to describe a behavior or interaction between a cell and its environment. To cope with this, our algorithms must be robust: they should work even if reality differs slightly from the model.

The complexity grows when controlling a community with different types of microbes. For instance, they might compete for the available food, which could result in the extinction of one of the microbe species.

Control algorithms that aim to regulate such a co-population must take into account the relation between two species, taking decisions that will ensure their survival and, consequently, help the work of bioengineers.

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