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April 24, 2005

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Bioluminescence: Science and Engineering Applications

Over the past quarter of a century many biological phenomenon have been studied in order to further both fundamental scientific knowledge and the ability to use these phenomenon in engineering applications. Bacterial bioluminescence is an excellent example of a phenomenon that has been studied in this way. As frequently occurs one set of people have investigated the issue from the scientific point of view, and another set, from the engineering. Thus while Engebrecht et al. have investigated the fundamental science ideas behind bacterial bioluminescence (1983), Ron Weiss and Thomas Knight have explored the engineering applications of this phenomenon (2000). This paper will explain the phenomenon of bacterial bioluminescence in detail and will describe its engineering applications.

Bioluminescence provides a method for quorum sensing. In this type of system the expression of a signal depends on the concentration of an autoinducer. This inducer is secreted by the cell that sends the signal (thus the autoinducer is called "self-secreted"). Due to the need for a high concentration of autoinducer, the signal is recognized only when the density of cells is high, not when the density is low. This type of system is favorable for engineering applications because the threshold dependent behavior provides a simple way of both distinguishing and controlling when the signal is on and when it is off.

Luminescent materials are often present in bacteria. Researchers understand that these luminescent bacteria provide favorable conditions to their hosts by helping them to attract prey, communicate among each other, and avoid predators (Engebrecht, 1983). The benefits to the bacteria themselves, however, are not as well understood. Though researchers lack knowledge about why bacteria benefit from their luminescent capabilities, they do understand most of the important components of this light production pathway. Engebrecht et al.'s work on the functions of bioluminescence from *Vibrio fischeri* illustrated that when the concentration of the autoinducer rose above the threshold value, light production would be catalyzed by luciferase (an enzyme). Engebrecht et al. were then able to locate the necessary genetic functions for this system on a cloned DNA from *V. fischeri*. Though Weiss and Knight's work focused on converting biological knowledge of this system to an engineering application, they also studied the operon sequence and provide basic biological information that Engebrecht et al. did not. For example, Weiss and Knight explain that the identity of the autoinducer described by Eberhard et al. (1981) was N-(3-oxohexanoyl)-3-amino-dihydro-2-(3H)-furanone (Weiss and Knight, 2001).

In addition to explaining the biology involved, including the sequencing, Weiss and Knight illustrated their biomimetic method in a simple and elegant manner. Weiss and Knight first constructed a series of plasmids of three types: preliminary, message transmitters, and message receivers. Since this was an engineering application, it was important to design a system whose biology was well understood and could be reproduced reliably. Thus when a promoter was needed to control the LuxI coding region, the Lac promoter was chosen. A Clonetech pPROTET.E332 plasmid was also used in order to enable the researchers to have control over the expression of the inserted gene; varying the level of a form of tetracycline provided this control (Weiss and Knight, 2001). The results Weiss and Knight reported both confirm the ability of their system to send constant and controlled signals and illustrate how the system was controlled. Weiss and Knight explained that the regulation derives from the fact that one cell controls – via the Tet operon – how much LuxI autoinducer synthesase is made. The amount of this signal then affects the second cell, since the synthesase is necessary for production of the *V. fischeri* autoinducer. This leads to control of the system and the threshold behavior described earlier.

There are a variety of aspects of this pathway that, from either the scientific or engineering point of views, are especially important. For science, it is important that the presence of bacteria with this pathway benefits their hosts. In both science and engineering it is important that the luminescence is controlled, so that autoinducer must past a threshold value for the signal to be recognized. (For science it is furthermore important that the system can also send a constant signal, in addition to a controlled one.) For engineering applications it is important that there are likely other similar pathways, so a complex system, combining many such pathways, may be used. This would be important for computing applications that need a number of variables. For engineering it is also important that promoters like Lac, which are very well understood, can be used.

← This is the case in nature. Not sure it has to hold true in other scientific application

Bacteria luminescence has been researched greatly during the past quarter of a century. It is an important subject because it has provided more insights into mechanisms used by marine creatures as well as symbiotic relationships, of which much is often unknown. This work is important not only for its additions to fundamental science, but also for the engineering ideas that it has spawned – ideas that may likely become realized in the future. For example, knowledge on this subject would allow scientists to create new genetically engineered species expressing this trait. The procedure described by Weiss and Knight may also provide a new mechanism of gene control for experimental applications.

Bioluminescence is thus one of many cases where the engineering applications of a scientific pathway appear to be much broader and of more importance than the scientific applications themselves. Weiss and Knight's work on an engineering application presents an effective signaling model that functions as a basic computing device / circuit. Since there are dozens of signaling molecules, this implies dozens of potential computational systems. Furthermore the threshold requirement means that it should be possible to produce a digital system – the type that is most often desired. Finally because the underlying biological pathway is well understood, and not overly complicated, the ease of designing these computational systems should not be overwhelming. Thus in the future, bacterial luminescence will likely find a variety of important engineering applications. pathways and their derivatives

Since the pathway of producing light in bacteria became well understood two decades ago, interest in the biological engineering applications of bacteria luminescence has increased dramatically. As circuits could be based not only on this particular signaling molecule, but dozens more, this technique presents an important design model with many significant engineering applications.

References

Engebrecht, J., Nealson, K., Silverman, M. (1983). Bacterial Bioluminescence: Isolation and Genetic Analysis of Functions from Vibrio fischeri. Cell, *32*, 773-781.

Weiss, R., Knight, T. F. (2001). Engineering Communications for Microbial Robotics. A. Condon (Ed.): DNA 2000. Lecture Notes in Computer Science, *2054*, 1-16.