Course Description: 21st century already is, and will continue to be, the century of biology. Thus, any aspiring engineer should be equipped with knowledge of biological systems and tools to model their quantitative aspects. This course offers an introduction to molecular and cellular biology from an engineering point of view. It assumes no prior knowledge of biology beyond the level of NS 101-102.

The course will start by introducing “the cell” as the smallest unit of life. In the context of cell growth, students will learn a simple strategy for solving differential equations numerically, which will be used throughout the course to model the energetic and informational aspects of life.

When discussing the energetic aspects, I will introduce some of the “voltages” that cellular energetics relies on and the “wires” needed to dissipate these voltages. We will see that many proteins (enzymes, transporters, channels) serve as wires for these voltages. In fact, because of their ability to "charge" one battery by "dissipating" another, these proteins can also be viewed as machines that convert energy from one form to another. We will see that, in order to work continuously, these molecular machines need to go through cycles of operational states. However, unlike the machines we are familiar with from everyday life, the operation of these molecular machines is random. We will learn how to mathematically model these random, cyclic machines.

In the second part of the course we turn from energy to information. We will see how other proteins (transcription factors) implement molecular logic gates, like the familiar AND, OR and NOT gates of digital electronics. We will consider the information (in bits) that these proteins “read” while doing their jobs. Then, we will bring several of these logic elements together and analyze the circuits that bacterial cells employ when making decisions about “eating” sugars other than glucose. When examining their dynamical responses, we will first model these control circuits as Boolean networks. This will allow us to develop intuition about the qualitative features of the responses without delving into more advanced mathematical modeling. At the end, we will perform a quantitative analysis of the dynamical responses of these information control circuits.

Evaluation:

<table>
<thead>
<tr>
<th>Evaluation</th>
<th>Percentage</th>
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<tbody>
<tr>
<td>Homework assignments</td>
<td>25 %</td>
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<tr>
<td>First exam</td>
<td>25 %</td>
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<tr>
<td>Second exam</td>
<td>25 %</td>
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<tr>
<td>Final exam</td>
<td>25 %</td>
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Course Content:

I. Cells and mathematical modeling (2 weeks)

II. Molecular energetics
   A. Batteries and wires in the cell (2 weeks)
   B. Proteins as random machines (2 weeks)
   C. Proteins are cyclic machines (2 weeks)

III. Molecular information
   A. Molecular logic gates and information (2 weeks)
   B. Information control circuits in the cell (2 weeks)
### Detailed Course Content:

#### Cells and mathematical modeling

<table>
<thead>
<tr>
<th>Date</th>
<th>Topic</th>
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<tbody>
<tr>
<td>Feb 4</td>
<td>General information about the course</td>
</tr>
<tr>
<td>Feb 5</td>
<td>Mathematical model of cell growth</td>
</tr>
<tr>
<td>Feb 11</td>
<td>Numerical solution of cell growth model</td>
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<tr>
<td>Feb 12</td>
<td>What is inside a cell?</td>
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<tr>
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<td><strong>HW 1: Logistic growth with MATLAB</strong> (due Feb 19)</td>
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<tr>
<td>Feb 18</td>
<td>ATP hydrolysis as a battery</td>
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<td>Feb 19</td>
<td>Equilibrium of chemical reaction</td>
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<td><strong>HW 2: Visualizing protein structures with VMD</strong> (due Feb 26)</td>
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<tr>
<td>Feb 25</td>
<td>ATP battery needs a wire (rates of reactions)</td>
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<tr>
<td>Feb 26</td>
<td>Proteins as “wires” for chemical batteries</td>
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<td><strong>HW 3: Adenylate kinase (ADK)</strong> (due Mar 4)</td>
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#### Batteries and wires in the cell

<table>
<thead>
<tr>
<th>Date</th>
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<tbody>
<tr>
<td>Mar 3</td>
<td>Membrane permeability for glucose and ions</td>
</tr>
<tr>
<td>Mar 4</td>
<td>Transporters and channels as machines</td>
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<tr>
<td></td>
<td><strong>HW 4: Permeation through lipid bilayers</strong> (due Mar 11)</td>
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<tr>
<td>Mar 10</td>
<td>Kinetic modeling of random transitions</td>
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<td>Mar 11</td>
<td>Transporters and channels as machines</td>
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<td><strong>HW 5: Random jumps between two states</strong> (due Mar 18)</td>
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#### Proteins as random machines

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<tr>
<td>Mar 17</td>
<td>Fast and slow processes</td>
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<tr>
<td>Mar 18</td>
<td>Approximate analysis of a 3-state cycle</td>
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<td><strong>HW 6: Phosphofructokinase</strong> (due Mar 25)</td>
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<td>Mar 24</td>
<td>Independent binding of multiple ligands</td>
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<td>Mar 25</td>
<td>Glucose Transporter as a 4-state machine</td>
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<td><strong>HW 7: Glucose transporter</strong> (due Apr 7)</td>
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<td>Semester Break</td>
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#### Molecular logic gates and information

<table>
<thead>
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<tbody>
<tr>
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<td>Eating lactose instead of glucose</td>
</tr>
<tr>
<td>Apr 15</td>
<td>Regulation of transcription</td>
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<td><strong>HW 8: Logic gates from activators and repressors</strong> (due Apr 22)</td>
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<td>Apr 21</td>
<td>Language and entropy (Claude Shannon)</td>
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<td>Apr 22</td>
<td>Information needed to find DNA binding site</td>
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<td><strong>HW 9: Information content of operator sequences</strong> (due Apr 29)</td>
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#### Cellular information control circuits

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<th>Date</th>
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<tbody>
<tr>
<td>Apr 28</td>
<td>Molecular Boolean networks</td>
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<tr>
<td>Apr 29</td>
<td>Motifs in information control circuits</td>
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<td><strong>HW 10: Boolean analysis of feed-forward motifs</strong> (due May 6)</td>
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<tr>
<td>May 5</td>
<td>Kinetics of protein production and degradation</td>
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<td>May 6</td>
<td>Mathematical analysis of coherent FF loop</td>
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<td>May 12</td>
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<td>Second exam</td>
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<tr>
<td>May ?</td>
<td>Final exam</td>
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