# Evolution through Programming

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## Assignment 7

Choose ONE question to answer.

### Question 1 - Conditional Response

**Background**

In the paper "A mathematical model for adaptive prediction of environmental changes by microorganisms" by Mitchell & Pilpel (2011), the authors explore how microorganisms like *E. coli* evolved to use predictive regulation strategies. These organisms can use one environmental stimulus (S1) as a cue for the likely arrival of a subsequent stimulus (S2).

The paper demonstrates that in predictable environments, cells benefit from a Conditional Response (CR) strategy where they prepare for S2 upon encountering S1, rather than a Direct Response (DR) strategy where they only respond when S2 appears.

**Assignment**

In real populations, not all cells may adopt the same strategy. Your task is to explore what happens when only a subset of cells (at frequency *f*) have a conditional response to S1.

**Objectives**

1. **Implement a mixed population model** where:
   * A fraction *f* of cells use the Conditional Response (CR) strategy
   * A fraction (1-*f*) of cells use the Direct Response (DR) strategy
2. **Create a 2D heatmap** showing:
   * X-axis: *p* (probability that S2 follows S1), range [0, 1]
   * Y-axis: *f* (frequency of conditional responders), range [0, 1]
   * Color scale: Fitness advantage of the mixed population
3. **Analyze the correlation** between *p* and *f* and explain your findings.

**Model Parameters**

Choose specific values for:

* **Δt** - delay between S1 and S2 (Choose the parameter based on the results from the paper)
* **η** - cost parameter (Choose the parameter based on the results from the paper)
* α = ln(2) (dilution/degradation rate)
* κ = benefit coefficient (you can vary this or use a fixed value)
* TS1 = duration of S1 exposure

You may use values based on the ones used in the paper.

**Mathematical Framework**

The fitness of a mixed population is:

Where the effective fitness depends on environmental predictability:

From the paper, the fitness difference between strategies is:

The average fitness advantage of having frequency *f* of conditional responders:

**Deliverables**

1. **2D heatmap** showing fitness advantage as a function of *p* and *f*
2. **Written analysis** addressing:
   * The correlation between *p* and *f*
   * Biological interpretation of your results
   * Under what conditions would a mixed strategy be favorable?

**Extras (OPTIONAL)**

* Consider why a population might maintain both strategies rather than fixing one
* Think about how environmental variability might affect the optimal *f*

**References**

Mitchell, A., & Pilpel, Y. (2011). A mathematical model for adaptive prediction of environmental changes by microorganisms. *PNAS*, 108(17), 7271-7276.