

# Methods for Open-box Analysis in Artificial Development

Adrian Grajdeanu

George Mason University  
Evolutionary Computation Lab  
Fairfax, VA, USA

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# Open-box Analysis in Artificial Development

## Why Open The Box?

- ▶ Understand the evolved mechanisms
- ▶ Manually purge the artifact
- ▶ Manually tweak the artifact

## How to Proceed?

- ▶ Gene activation map
- ▶ Chemical concentration monitors
- ▶ Environmental features ablation
- ▶ Gene suppression
- ▶ Modeling the regulatory network
- ▶ Subsystem simulation

# The Self-Repair Experiment

## The Task

- ▶ Start with an egg-cell
- ▶ Grow a colony of cells to a certain size
- ▶ Maintain the size
- ▶ Environment randomly kills patches of cells
- ▶ Detect damage and self-repair

# The Self-Repair Experiment

## Experimental Details

- ▶ ADS framework
  - ▶ internal and external protein concentrations
  - ▶ a gene is an **if <condition> then <action>** rule
  - ▶ genome is a collection of rules/genes evaluated in sequence
  - ▶ variable length representation
  - ▶ all cells share same genome
- ▶  $27 \times 27$  grid seeded in center with egg
- ▶ 4 proteins configured (p0 – p3)
- ▶ Evolutionary algorithm: ES(2+16)

# The Self-Repair Experiment

## Desired Behavior Has Evolved

```
genome [
  condition-2 > p0 0.90625 p3 0.210938 # g00
  action-neighbor-affinity p2 -0.226562
  condition-1 >= p0 -0.867188 # g01
  action-none # g02
  condition-2 > p0 0.78125 p2 0.210938 # g02
  action-protein consume p2 -0.695312
  condition-0 # g03
  action-protein absorb p1 0.460938
  condition-2 <= p0 -0.59375 p2 -0.390625 # g04
  action-protein eliminate p1 0.789062
  condition-0 # g05
  action-neighbor-affinity p0 0.0078125

condition-0 # g06
  action-protein absorb p0 -0.46875
condition-0 # g07
  action-protein eliminate p2 -0.09375
condition-1 > p1 -0.96875 # g08
  action-protein eliminate p2 -0.484375
condition-2 <= p0 0.78125 p1 -0.210938 # g09
  action-protein eliminate p1 -0.390625
condition-0 # g10
  action-protein consume p0 -0.148438
condition-1 < p0 -0.539062 # g11
  action-protein consume p0 -0.664062
condition-1 < p0 -0.101562 # g12
  action-protein produce p0 0.296875
condition-1 <= p0 -0.578125 # g13
  action-none # g14
condition-1 >= p2 -0.859375 # g14
  action-protein produce p0 -0.65625
condition-2 >= p0 -0.445312 p0 0.257812 # g15
  action-protein produce p3 -0.40625
condition-1 < p3 0.015625 # g16
  action-protein absorb p2 0.992188
condition-0 # g17
  action-none # g18
condition-0 # g18
  action-neighbor-affinity p3 0.34375
condition-0 # g19
  action-proteins-affinity # g19
condition-1 >= p2 -0.46875 # g20
  action-divide # g21
condition-0 # g21
  action-protein absorb p2 -0.484375
condition-0 # g22
  action-protein absorb p2 -0.476562 # g22
condition-1 >= p1 -0.976562 # g23
  action-protein produce p2 0.835938 ]
```

# The Self-Repair Experiment

Understanding the Evolved Mechanism of Self-Repair

## How to Proceed?

- ▶ Gene activation map
- ▶ Gene suppression
- ▶ Environmental features ablation
- ▶ Chemical concentration monitors
- ▶ Modeling the regulatory network
- ▶ Subsystem simulation

# Chemical Concentration Monitors

Protein p0 Concentrations

Internal

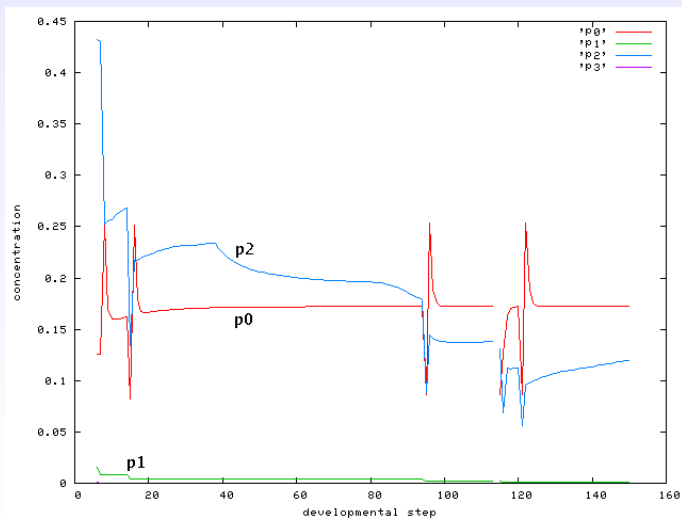
External

Protein p2 Concentrations

Internal

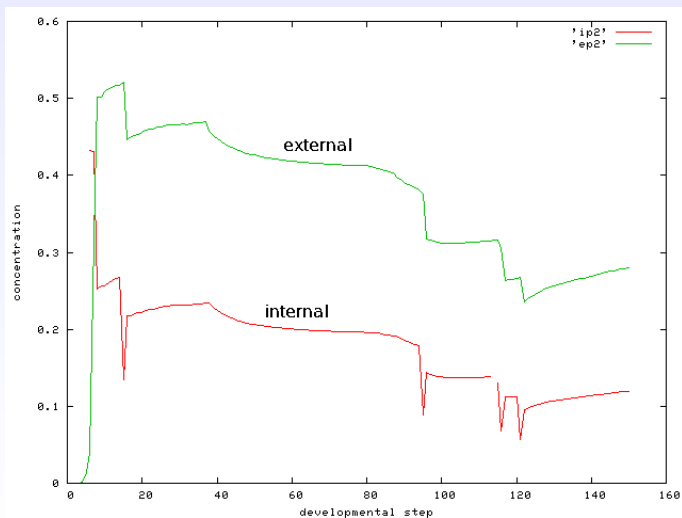
External

# Internal Chemical Concentrations in a Typical Cell



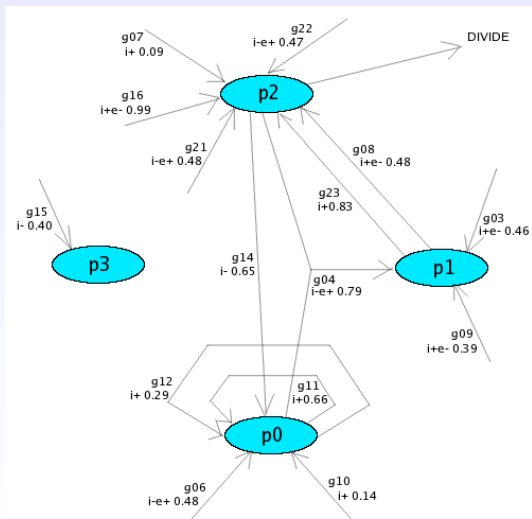


# Typical Internal and External Protein p2 Concentrations



# Modeling the Regulatory Network

Use Gene Activation Map for a cell in stationary regime.



What does this say?

# Protein p0 Subsystem Simulation

## Stabilizing the Concentration

### Genomic Code:

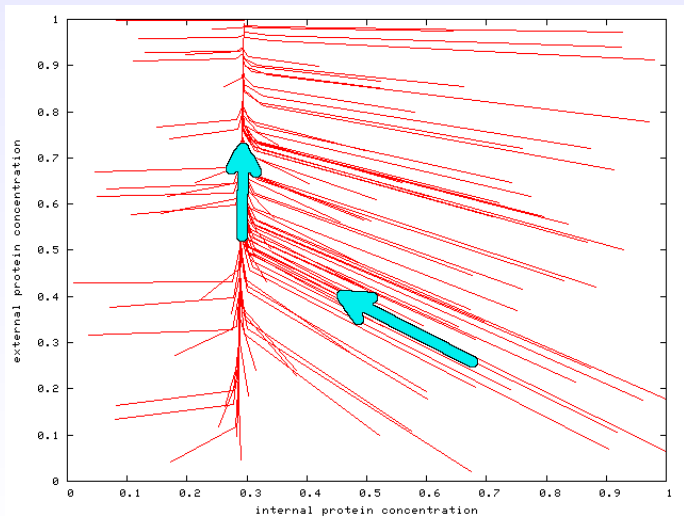
```
genome [  
...  condition-0                                # g10  
      action-protein consume p0 -0.148438  
      condition-1 < p0 -0.539062              # g11  
      action-protein consume p0 -0.664062  
      condition-1 < p0 -0.101562             # g12  
      action-protein produce p0 0.296875  
...  condition-1 >= p2 -0.859375            # g14  
      action-protein produce p0 -0.65625  
... ]
```

### Equivalent Recurrent System:

$$\begin{cases} int_{t+1} = 0.274607 + 0.0367324 \times int_t + 0.032411 \times ext_t \times int_t \\ ext_{t+1} = ext_t + 0.46875 \times int_t - 0.46875 \times ext_t \times int_t \end{cases}$$

# Protein p0 Subsystem Simulation

## Stabilizing the Concentration (continued)



# Protein p2 Subsystem Simulation

## Self-Repair Mechanism Revealed

### Genomic Code:

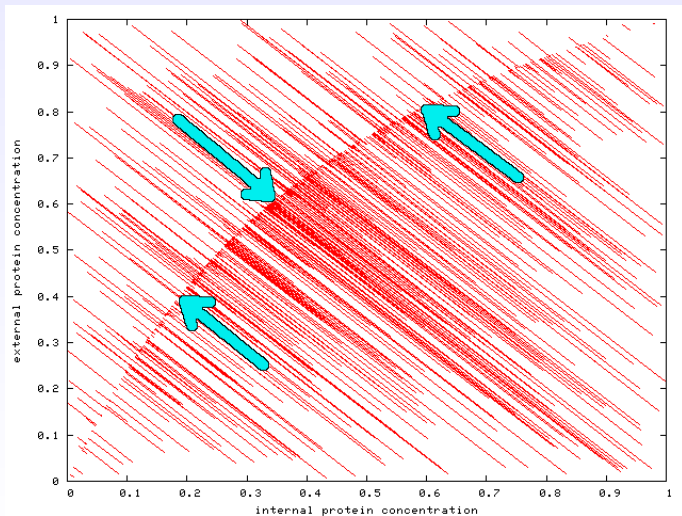
```
genome [  
... condition-0 # g07  
    action-protein eliminate p2 -0.09375  
... condition-1 < p3 0.015625 # g16  
    action-protein absorb p2 0.992188  
... condition-0 # g21  
    action-protein absorb p2 -0.484375  
    condition-0 # g22  
    action-protein absorb p2 -0.476562  
... ]
```

### Equivalent Recurrent System:

$$\begin{cases} int_{t+1} &= a_{0,0} + a_{0,1} \times ext_t + a_{1,0} \times int_t + \cdots + a_{8,8} \times int_t^8 \times ext_t^8 \\ ext_{t+1} &= b_{0,0} + b_{0,1} \times ext_t + b_{1,0} \times int_t + \cdots + b_{8,8} \times int_t^8 \times ext_t^8 \end{cases}$$

# Protein p2 Subsystem Simulation

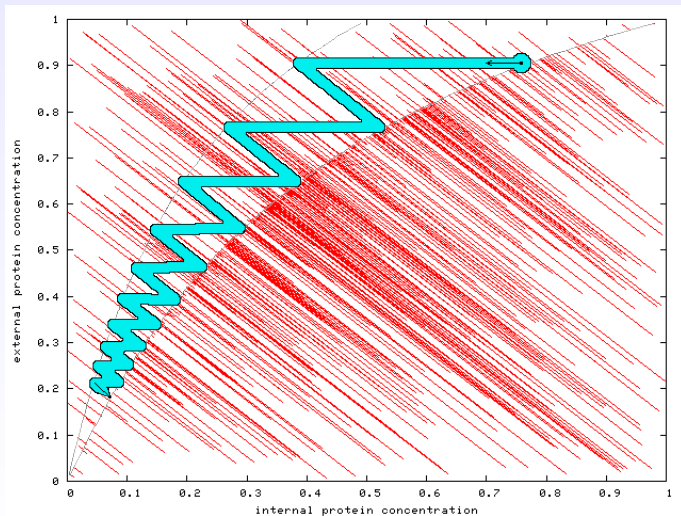
## Self-Repair Mechanism Revealed (continued)



# Protein p2 Subsystem Simulation

## Self-Repair Mechanism Revealed (continued)

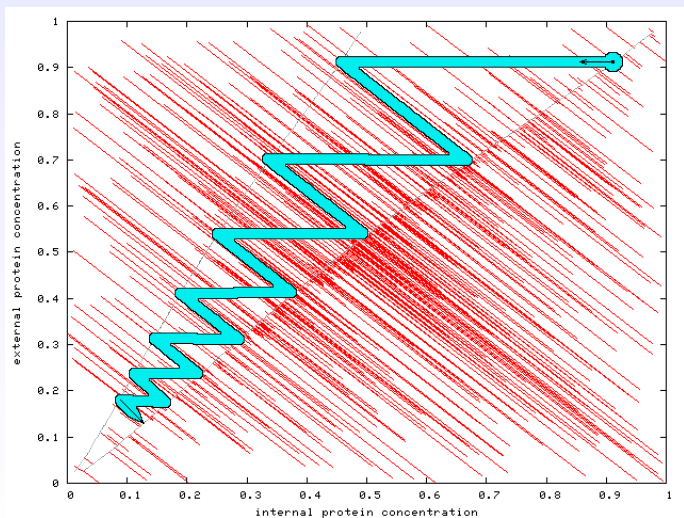
'Healthy' Self-Repair:



# Protein p2 Subsystem Simulation

## Understanding Aging

Either Gene g21 or Gene g22 Suppressed  $\rightarrow$  Premature Aging:

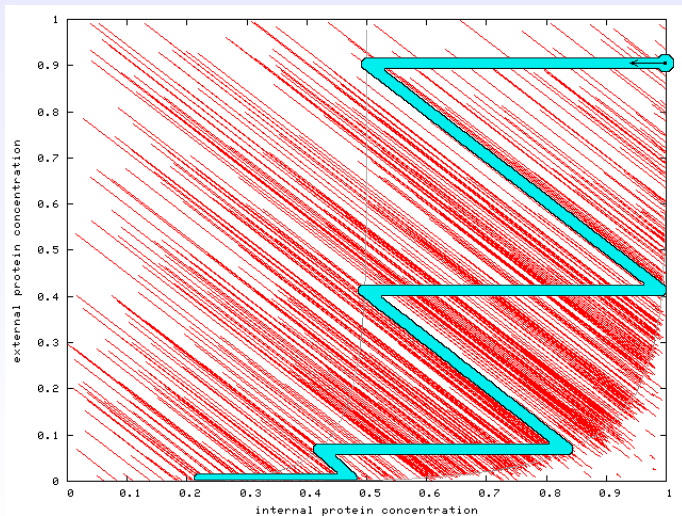




# Protein p2 Subsystem Simulation

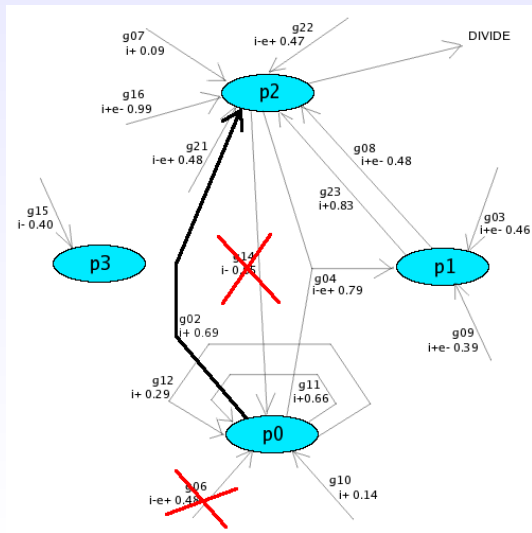
Understanding Aging (continued)

Both Gene g21 and Gene g22 Suppressed  $\rightarrow$  Accelerated Aging:



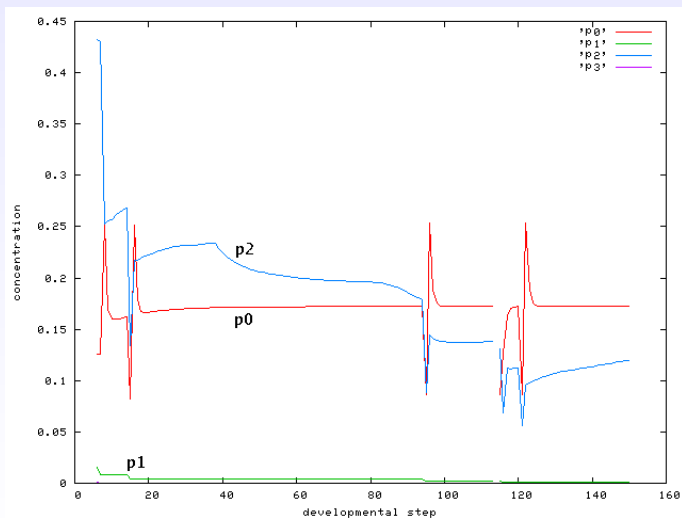
# Modeling the Regulatory Network – Revisited

## Cause of Cancerous Behavior



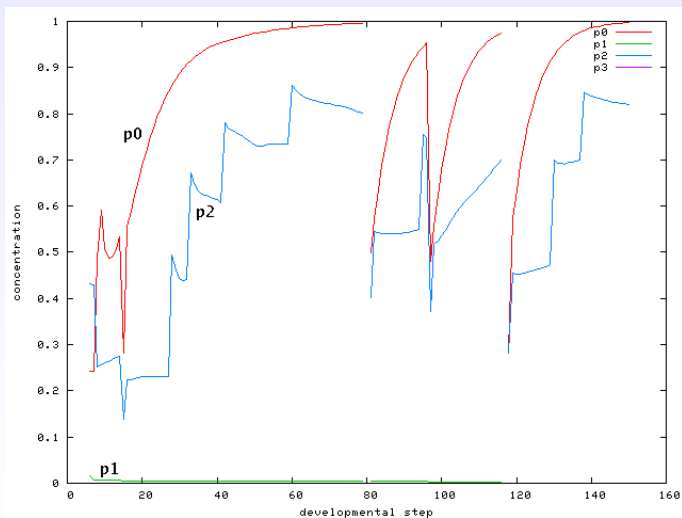
# Internal Chemical Concentrations in a Typical Cell

(Repeat Slide)



# Internal Chemical Concentrations in a Typical Cell

Gene g14 Suppressed; Regulation Mechanisms Fail



# Conclusions

## Relevance

- ▶ Engineers care 'how' an artifact works
- ▶ Open-box analysis can provide the necessary understanding
- ▶ Investigative methods can be borrowed from biology

## Methods For Open-box Analysis in Artificial Development

- ▶ Gene activation map
- ▶ Gene suppression
- ▶ Environmental features ablation
- ▶ Chemical concentration monitors
- ▶ Modeling of the regulatory network
- ▶ Subsystem simulation

# The End

Thank You!

Questions?

# Protein p2 Subsystem Simulated

## Understanding Aging

From Gene Suppression experiments, g21 and g22 induce aging.

Normal

Premature

Accelerated

g22  
suppressed

g21 and g22  
suppressed