# The Baldwin Effect

## A New Factor in Evolution at work in a Simulation

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# A Little Evolutionary History…

Two Theories…

- Lamarckism

  - **<u>direct inheritance</u>** of characteristics that individuals gained during their lifetime

  - evolution happens on occasion in rapid jumps

- Darwinism

  - evolution can be explained by natural selection coupled with diversity through mutations

  - evolution happens in very small steps

# A Little Evolutionary History…

- James Mark Baldwin published “A New Factor In Evolution” in 1896
- C.L. Morgan and H.F. Osborn proposed some of the same concepts on their own

JAMES MARK BALDWIN

# A Little Evolutionary History


THE BALDWIN EFFECT IS BORN

# How does it work??

There are two steps:

1. phenotypic plasticity present in individual organisms allows them to adapt to partially successful mutations

the ability of an organism to adapt to its environment over its lifetime

such as…ability to tan with exposure to the sun, the ability of muscles to increase in strength with exercise, the ability to form a callus with exposure to abrasion, and most of all the ability to learn

If fitness is increased by mutation, this mutation will increase in the population by natural selection

# How does it work??

But…phenotypic plasticity is costly

Costly because…

- Learning requires time and energy (trial and error)
- Learning is dangerous (experimentation)

It is advantageous to avoid deadly enemies by instinct, or for apes to be born with calluses on their hands and feet

So…

# How does it work??

2. Learned behaviors become instinctive behaviors

   - eventually rigid mechanisms replace plastic ones over time
   - different from Lamarckian evolution because the genotype is not directly altered
   - like Waddington "canalization"

This is all well and good, but how does an organism come to be modified during its life??

# On Modification

- Three categories that produce modifications, adaptations, or variations

  1. Physico-genetic

     - "*the physical agencies and influences in the environment which work upon the organism to produce modifications of its form and function*"

     - accidental changes

  ex. Chemical agents, changes in temperature, hindrances to growth

# On Modification

- Three categories that produce modifications, adaptations, or variations

  2. Neuro-genetic

     - "*modifications which arise from the spontaneous activities of the organism itself in the carrying out of its normal congenital functions*"

     - rising to the occasion

     - Morgan called this the selective property of the nervous system

present at birth but not necessarily hereditary; acquired during fetal development

# On Modification

- Three categories that produce modifications, adaptations, or variations

  3. Psycho-genetic

    - "*the great series of adaptations secured by conscious agency*"

    - intelligent processes

    - lessons

  ex. Imitation, pleasure and pain, reasoning, experience

  How do these modifications serve Evolution you ask?

# Serving Evolution

Somehow organisms are able to find favorable conditions and repeat adaptive movements

Thus, organisms are able to learn new movements and behaviors that deal with all three categories, (modify themselves)

These modifications are all combined and employed to keep organisms alive

So, organisms with useful modifications reproduce more, and…

# Serving Evolution

Advantageous variations are used more often in each generation that follows

In this way, intelligence is preserved, or better, the ability to learn is preserved from one generation to the next

Another route….

# Social Heredity

Other creatures are present in the environment, and neuro-genetic and psycho-genetic accommodations involve these other creatures

Functions of older creatures are observed and picked up upon by younger creatures through imitation, experience, or instruction

Only imitative actions that help an organism survive are preserved

- Imitative actions that are harmful to an organism, when performed will help natural selection kill that organism (and others like it) off

# Social Heredity

Called the concept this for two reasons:

1. physical functions are handed down from generation to generation

2. physical heredity is directly influenced
   - variations are kept in existence
   - directs ontogenetic adaptation
   - the range of possible congenital variations of next generation are set

# A Simulation (Bugs!)

Robert French and Adam Messinger showed that the Baldwin Effect can alter the course of evolution at the genotypic level in a simulation

Plasticity at the phenotypic level produces directed changes at the genotypic level

How do they show this??

# A Simulation (Bugs!)

- A discrete time simulation of free-acting agents, or bugs, in a 100x100 matrix
- Each cell contains one bug at most
- The matrix is populated randomly with bugs that have randomized genotypes and also food piles with a uniform size
- More food is randomly placed at each timestep of the simulation
- Each bug has a food counter

  - The food counter is decremented for movement, metabolism, and reproduction

  - if it drops below zero that bug dies

# A Simulation (Bugs!)

- Bugs have ability to sense food piles in the four cells which surround them
- Four things are done at each timestep:

1. Metabolize- “existence tax” is subtracted from food count
2. Eat- they eat a pre-specified amount of food if their cell contains any
3. Reproduce- can be asexual or sexual; bugs can reproduce if their food counter is above a pre-specified reproduction threshold
4. Move- bugs move to the cell with the most food, if all cells have the same amount they move the same way they did before

# A Simulation (Bugs!)

- Each bug's genetic code is a fixed-length gene consisting of 1's or 0's
- One bit pattern is determined to be superior (dubbed the "Good Gene"
- The GG corresponds to a GP ("Good Phene"), so

  - bugs with the GG will possess the GP
- But…bugs can learn the GP

  - the closer a bug is to the GG, the easier it is to learn the GP
- The GP makes the bug either move, metabolize, or reproduce

  more efficiently by reducing how much it is docked for each of these activities

# A Simulation (Bugs!)

- Reproduction is either asexual or sexual

Asexual:

- if a bug has enough food to reproduce, it copies itself

- there is a mutation rate parameter that determines the probability that a bit will be copied wrong

- a pre-specified amount of food is transferred from the parent’s food counter to the child’s

# A Simulation (Bugs!)

- Reproduction is either asexual or sexual

Sexual:

- if a bug has enough food to reproduce, it checks for a bug in its surrounding cells

- if it finds a mate, it produces a child whose gene is determined by crossover of the parent's genes at a random point

- the mutation parameter is included

- pre-specified amount of food is taken from only the moving bug's food counter, not its mate's, and is given to the child

# A Simulation (Bugs!)

- How is learning determined??

  Two factors play a role:

  1. phenotypic plasticity, how difficult it is to learn the GP

  2. how much the bug benefits from learning the GP

# A Simulation (Bugs!)

1. Phenotypic plasticity

- each bug's genotype is a certain distance from the GG
- using this distance, the probability that a bug will learn the corresponding GP is determined by a phenotypic plasticity curve

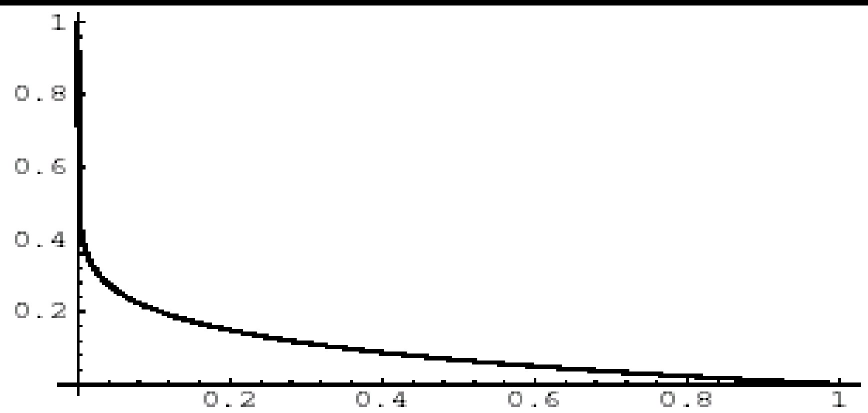
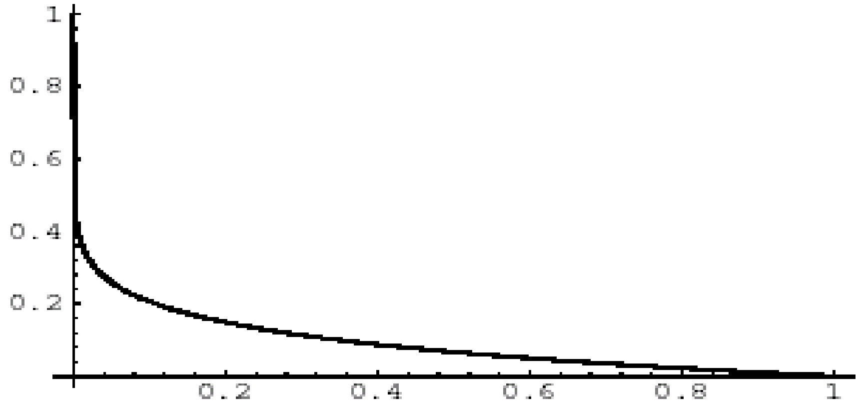



*Figure 1*: A phenotypic plasticity curve ($\rho = 0.1$) showing the probability of learning a Good Phene based on hamming distance from the Good Gene (if 20% of an agent's bits differ from the Good Gene, it will have a 15% chance of learning the Good Phene).

# A Simulation (Bugs!)

1. Phenotypic plasticity

- X-axis: # of bits differing from the GG/ total # of bits
- Y-axis: probability of learning the GP

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# A Simulation (Bugs!)

1. Phenotypic plasticity

- if the bug is close to the GG, it will have a better probability of learning the GP
- whether or not is actually learns the GP is done stochastically based upon its probability

# A Simulation (Bugs!)

1. Phenotypic plasticity

- shape of this curve depends upon how easy or difficult the GP is to learn

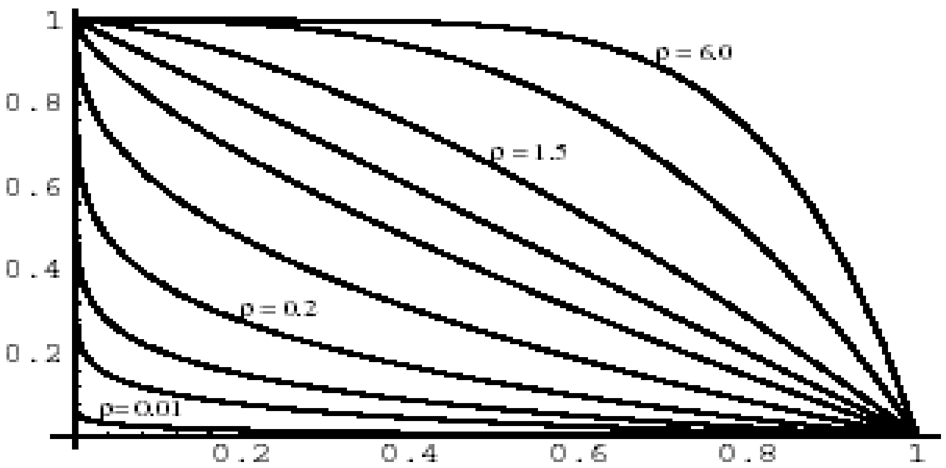



*Figure 2*: Curves showing varying degrees of phenotypic plasticity: $y=1-x^{\rho}$, where $\rho$ is phenotypic plasticity associated with a particular Good Phene

# A Simulation (Bugs!)

## 2. How much does the bug benefit?

- if the advantage of learning GP is very low, the population of bugs might not move in the direction of the GG
- but, if the advantage is very high, any bug that learns the GP will survive and the GG will be eventually present in all bugs

For example….

- if the GP was “energy taxes drop to zero”, once the GG was found by mutation it would dominate the pop because the bug that found it could survive and reproduce with no food

# Results of Bugs!

- Simulation 1

  - bugs reproduce asexually

  - the GP decreased the amount of energy docked by moving

  - thus, bugs born with the GG had a GP that allowed it to move around more efficiently than bugs without the GP

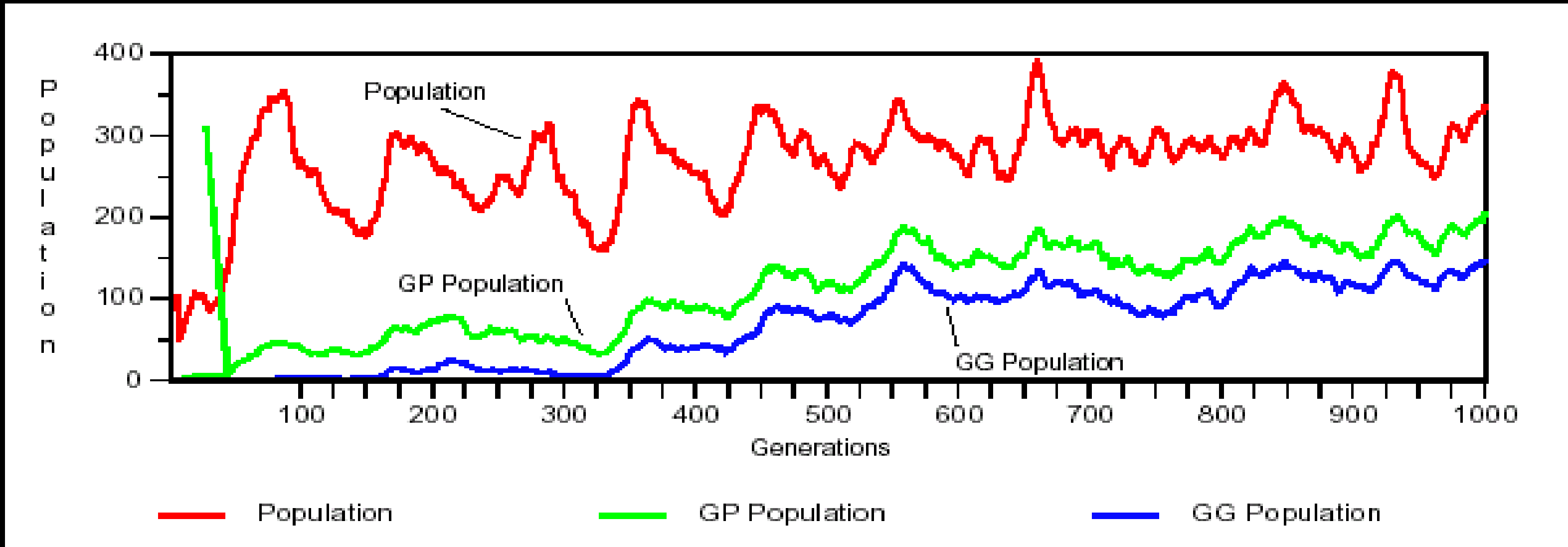
  - the phenotypic plasticity for the GP was 0.1 (not easy or difficult to learn)

# Results of Bugs!

- Simulation 1

  Graph shows the evolution of a population where the GP is being learned

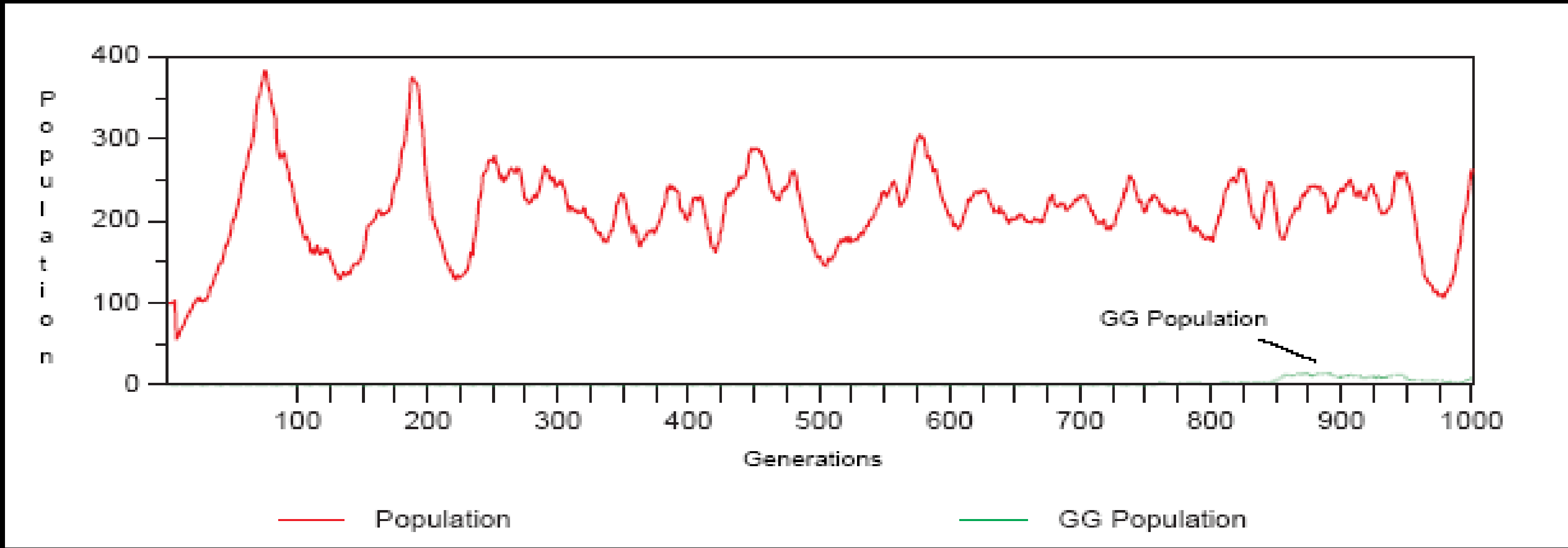
  total population    bugs that have GP (learned or born)    bugs born with GG



# Results of Bugs!

- Simulation 1

  Graph shows the evolution of same population with no learning
  - genotype does not change



# Results of Bugs!

- Simulation 1

Findings:

- half of the pop learned the GP by about 500 generations
- there is a consistent, overall increase in the total pop which is directly related to the benefit that the GP confers
- the number of bugs that have the GG increases, but is never higher than the number of bugs that have the GP (by being born with the GG or learning it)
- by 5,000 generations almost all bugs have the GP and around 70% have the GG
- once entire pop has the GP, the difference between the total pop and the pop that has the GG is directly proportional to phenotypic plasticity

# Results of Bugs!

- Simulation 1

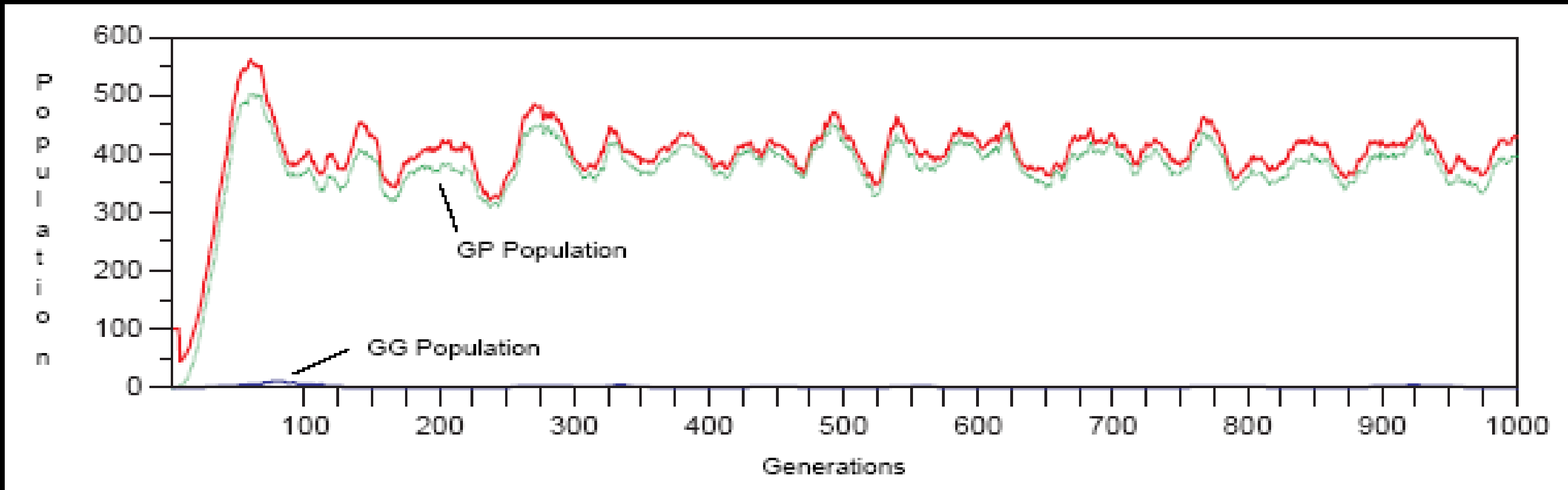
So, the Baldwin Effect has been demonstrated because the ability to learn the GP has a significant influence on the evolution of the genotype

# Results of Bugs!

- Simulation 2

Findings:

- as phenotypic plasticity increases, there is an increase in bugs with the GG
- but…eventually the number of bugs with the GG starts to decrease
- and…for extremely high plasticity there is not a push towards a GG pop



# Results of Bugs!

- Simulation 2

Conclusions:

- if plasticity is too high, all bugs will possess the GP, so there is no reason for more genotypic evolution

- as we saw earlier, if plasticity is too low, there is no shift in the pop towards the GG

# Results of Bugs!

- Simulation 2

Shown topographically

- the Baldwin Effect disappears for high and low plasticities

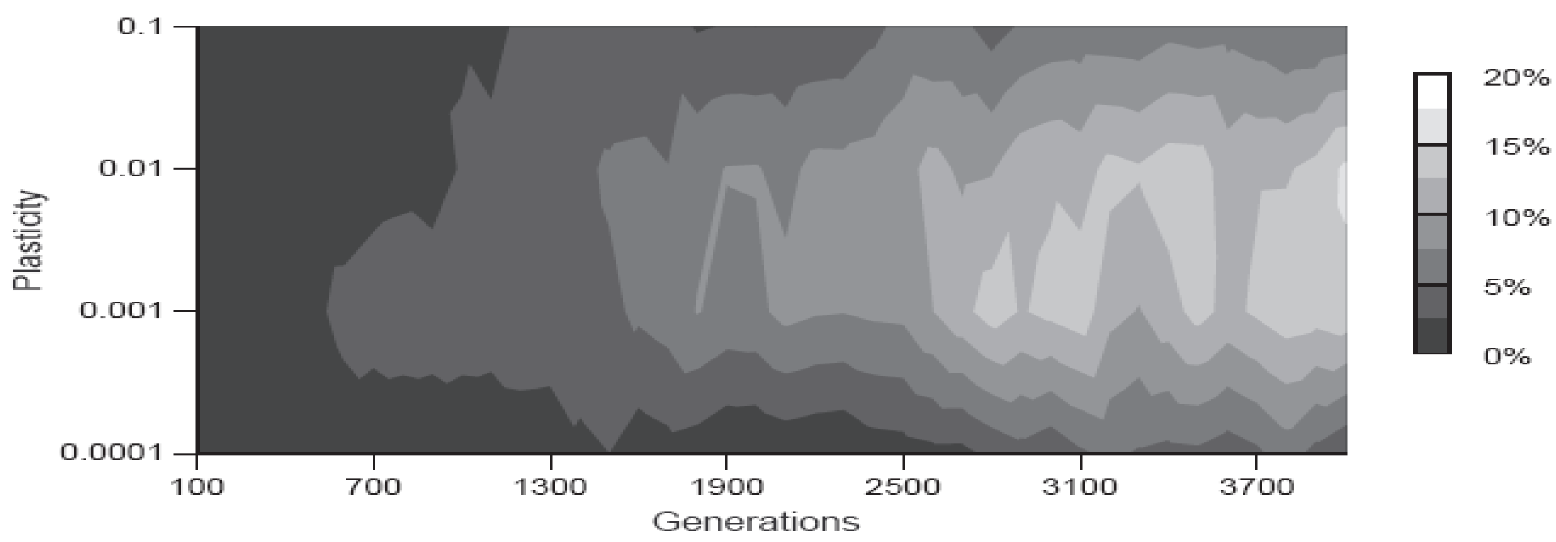



*Figure 6:* The effects of differing phenotypic plasticities on the evolution of the Good Gene in the population (lighter areas indicate higher GG percentages)

# Results of Bugs!

- Simulation 3

  - Baldwin Effect is affected by selective advantage

  - if advantage is non-existent or very small, there will be little or no GG increase in pop

    bugs with the GP will not survive better than those without it

  - if advantage is very big, even if plasticity is very low, after a few bugs find the GG

  they dominate the population quickly (next slide)

    bugs with the GG have such a better chance of survival

# Results of Bugs!

- Simulation 3
  - Selective advantage is very high and phenotypic plasticity is very low

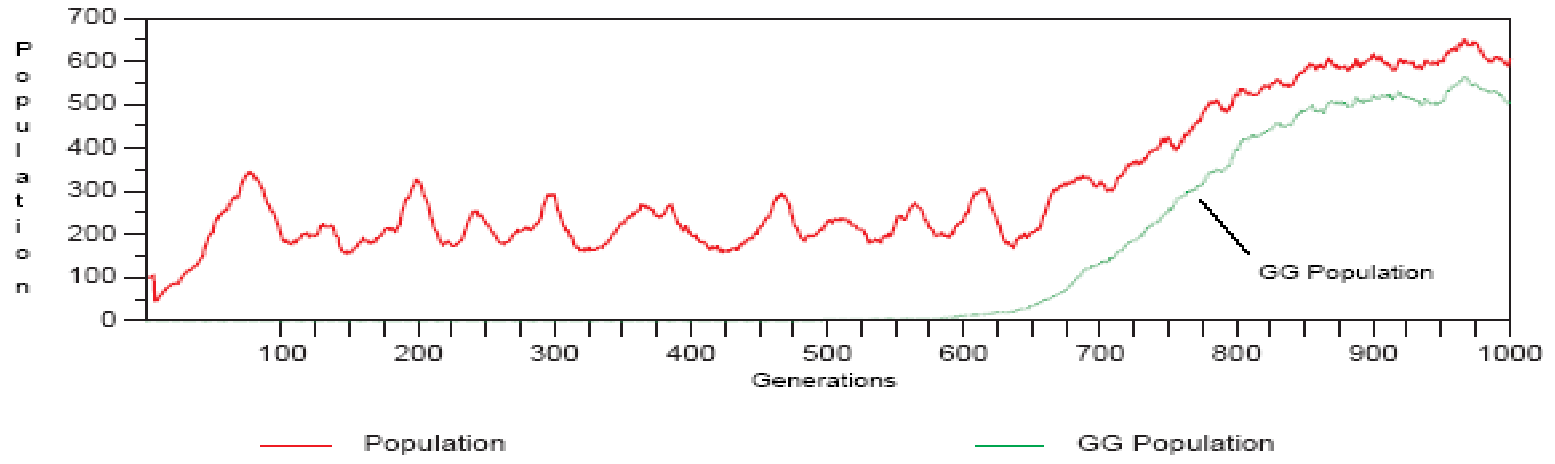
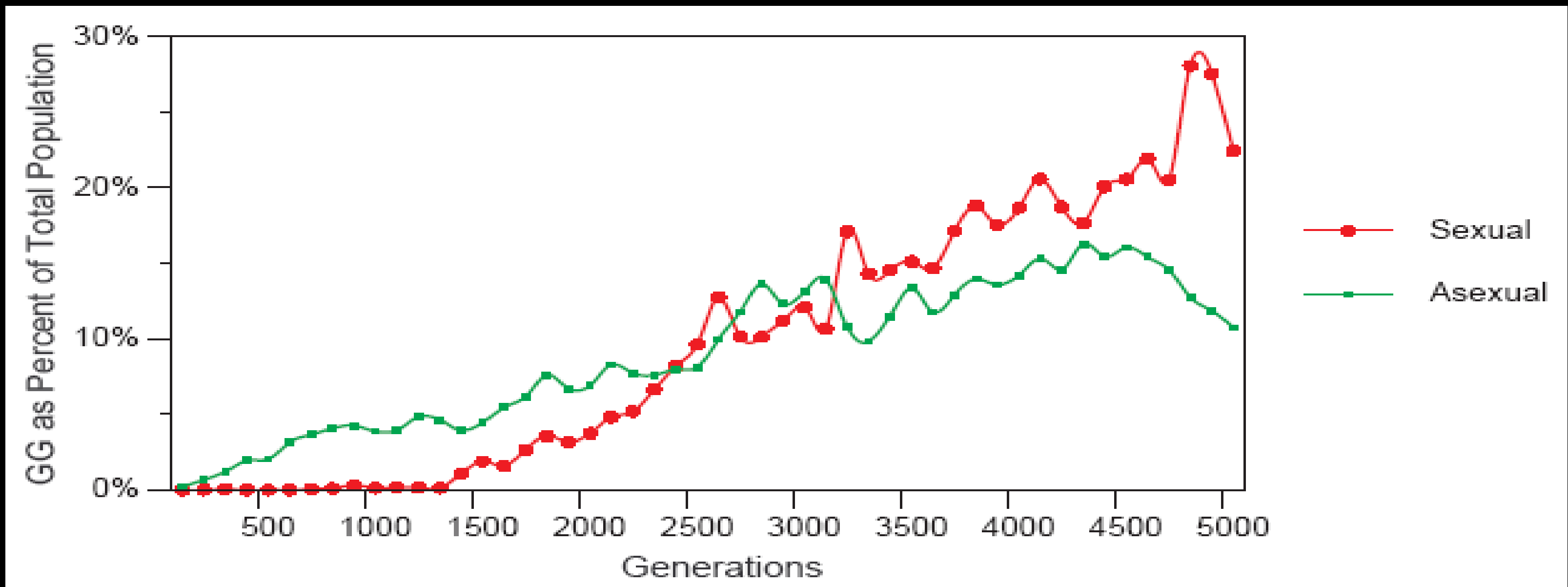



*Figure 7*
Effects on genotypic evolution of a *very* Good Phene

# Results of Bugs!

- Simulation 4

  - sexually reproducing bugs had higher concentration of GG bugs than asexual
  - in equal total pops, GG pop increased faster in sexually reproducing pops (graph)



# Conclusions from Bugs!

- The Baldwin Effect can be demonstrated in a simulated population

  - the ability to learn at the phenotypic level effected the genotypic evolution

  - phenotypic plasticity and the advantage that the GP confers have an impact on the amount of genotypic change

  - moderate levels of plasticity are a lot better at producing genotypic evolution than very high or low levels

  - the Baldwin Effect is more pronounced in populations that produce sexually

# References


- “Genes, Phenes and the Baldwin Effect: Learning and Evolution in a Simulated Population” by Robert M. French and Adam Messinger
  http://www.ulg.ac.be/cogsci/rfrench/baldwin.pdf
- “A New Factor in Evolution” by James Mark Baldwin
  http://spartan.ac.brocku.ca/~lward/Baldwin/Baldwin_1896_h.html
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  http://www.apperceptual.com/baldwin-editorial.html