Symbiosis as a Mechanism for building Complex Adaptive Systems: A Review

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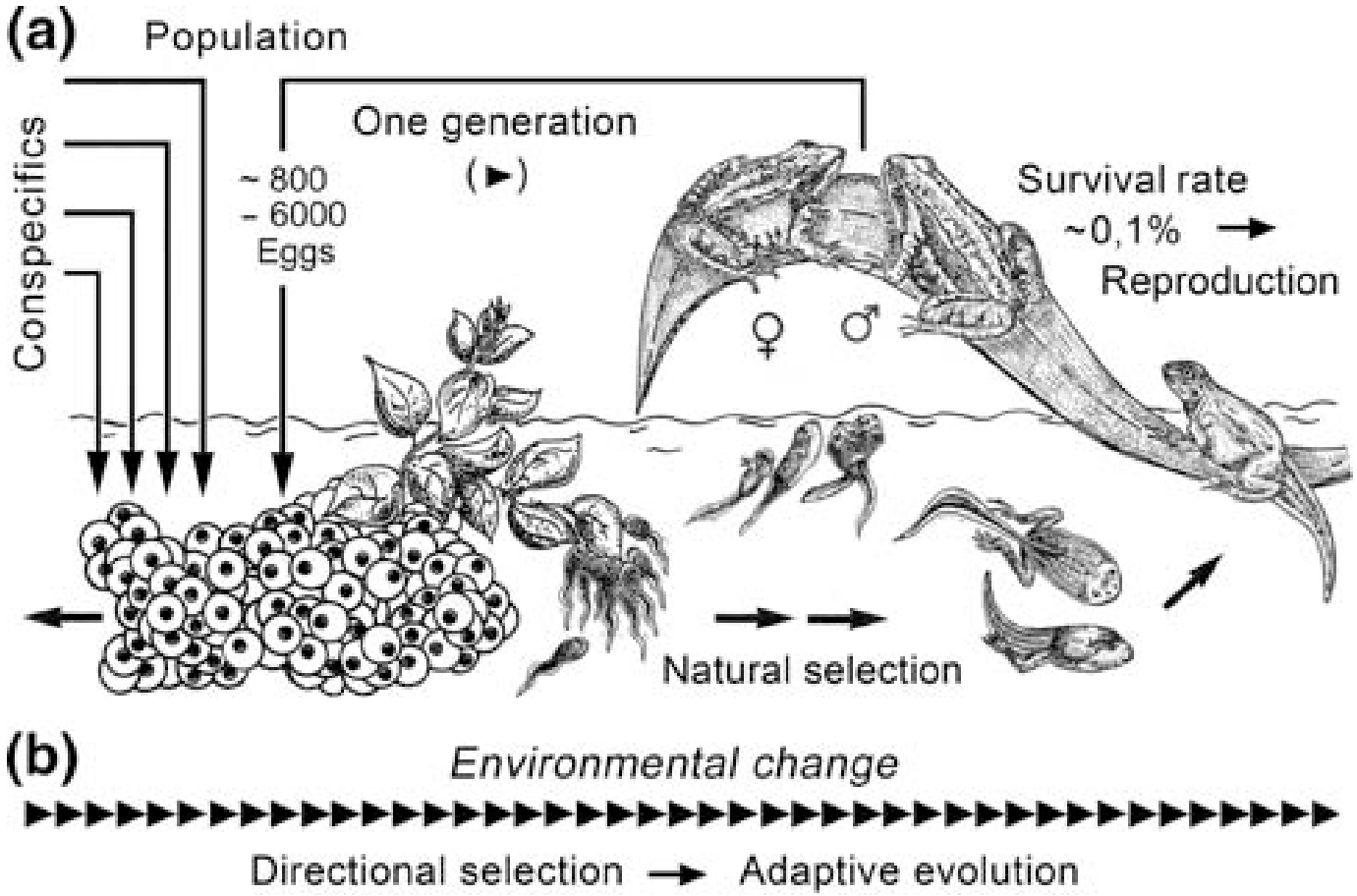
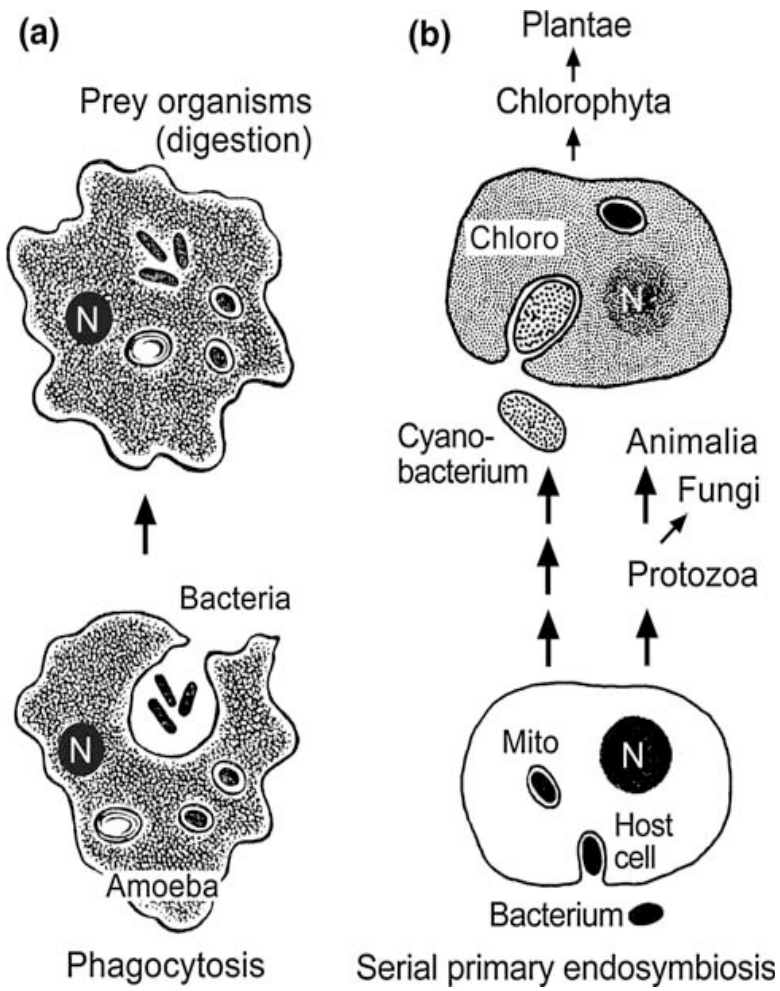
Principle of Natural Selection

Kutschera (2009)

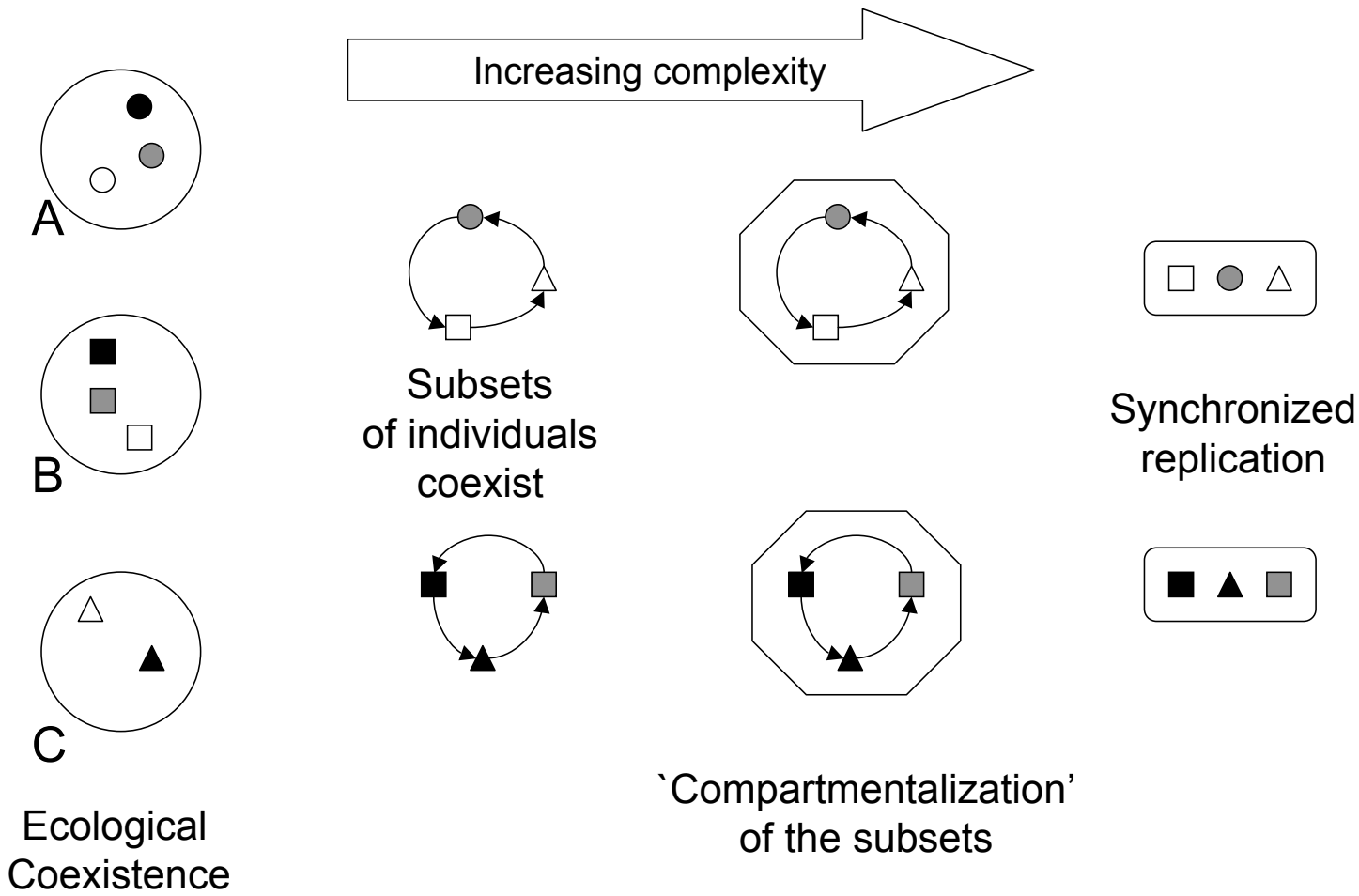


Serial Primary Endosymbiosis

Kutschera (2009)



Abstract Model of Symbiosis:
Maynard Smith (1991)



Continuum of Symbiosis:

Daida *et al*. (1996)

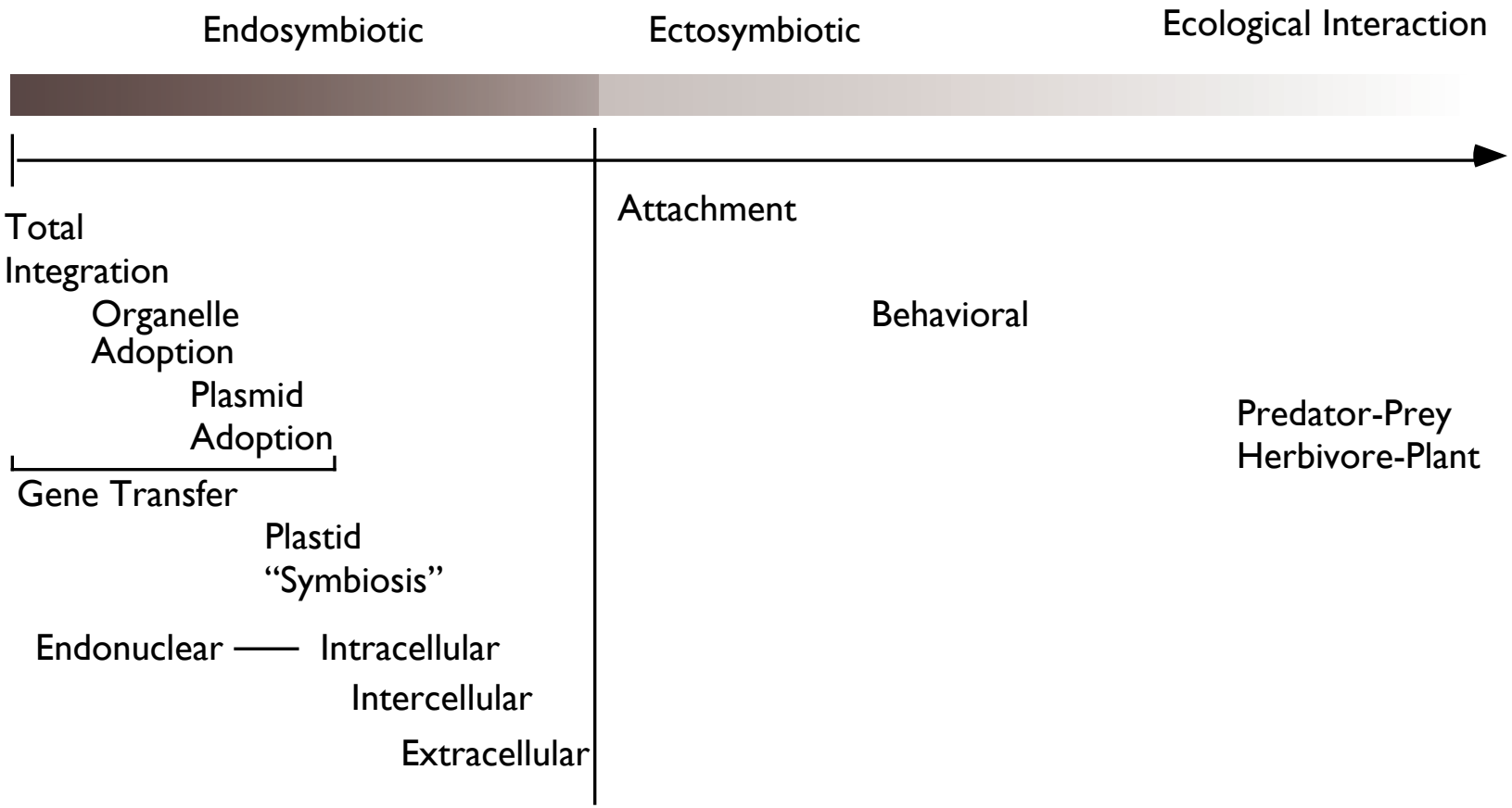


Figure 1. Continuum of interaction between dissimilar species.

Relationships

Margulis (1991)

- Spatial
  - Degree of physical separation existing between partners
- Temporal
  - Degree of permanence associated with a partnership
- Metabolic
  - Communication between symbionts
- Genetic
  - Degree of alignment between host and symbionts
- Coevolutionary

Coevolutionary Relations in Symbiosis

Coevolutionary Relation	Partner A	Partner B
Mutualism	Benefit	Benefit
Competition	Deteriorate	Deteriorate
Amensalism	No change	Deteriorate
Parasitism	Benefit	Deteriorate
Commensalism	No change	Benefit
Altruism	Deteriorate	Benefit

Some Pragmatics

- **Hosts**
  - **Who** gets to become a host ?
- **Symbionts**
  - How is symbiont context / communication defined ?
  - Who gets to become a symbiont ?
- **External factors**
  - Role of the wider ecosystem ?
  - Interaction between different hosts ?

Example Symbiotic Models I:
Genetic Relations

Watson and Pollack (2003)

A	**- - - - 1 - - - - 0 0 - 1 - -**
B	- - 1 - 0 - - - 0 - 1 - - - -
A+B	- - 1 - 1 - - - 0 0 0 - 1 - -

Provide a sample of 'contexts' for elitist comparison of child to parents

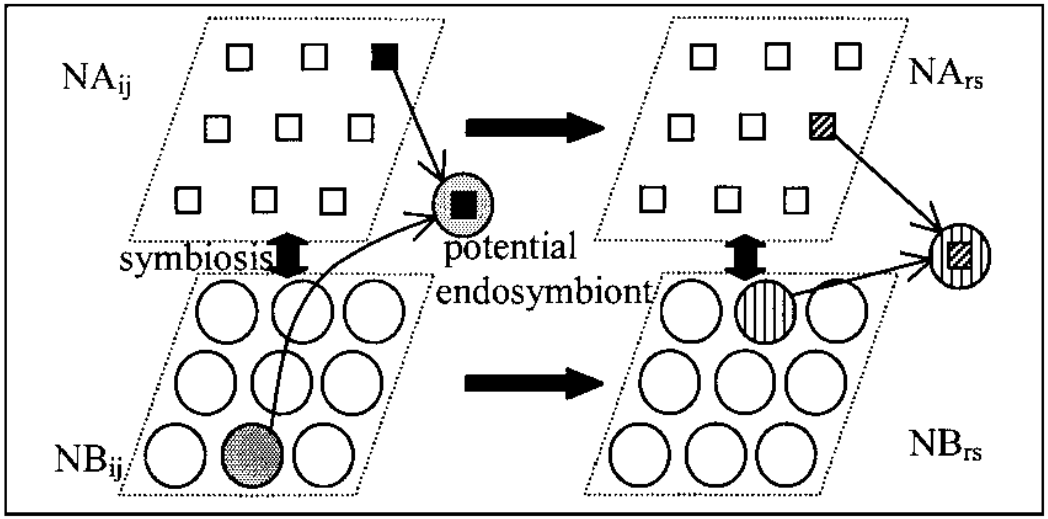
For all contexts: F(A+B) >> F(A), F(B)

Where '>>' denotes Pareto dominance

Example Symbiotic Models II:
Spatial Relations

Competition

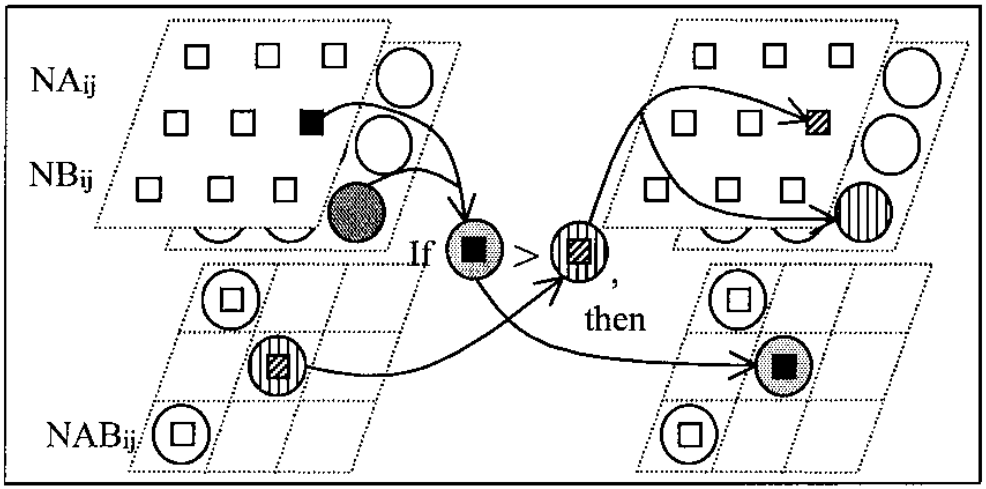
Kim *et al*. (2001)



(a) Cooperation of NA$_{ij}$ with NB$_{ij}$ and generation of a potential endosymbiont.

Replacement – Pt 1

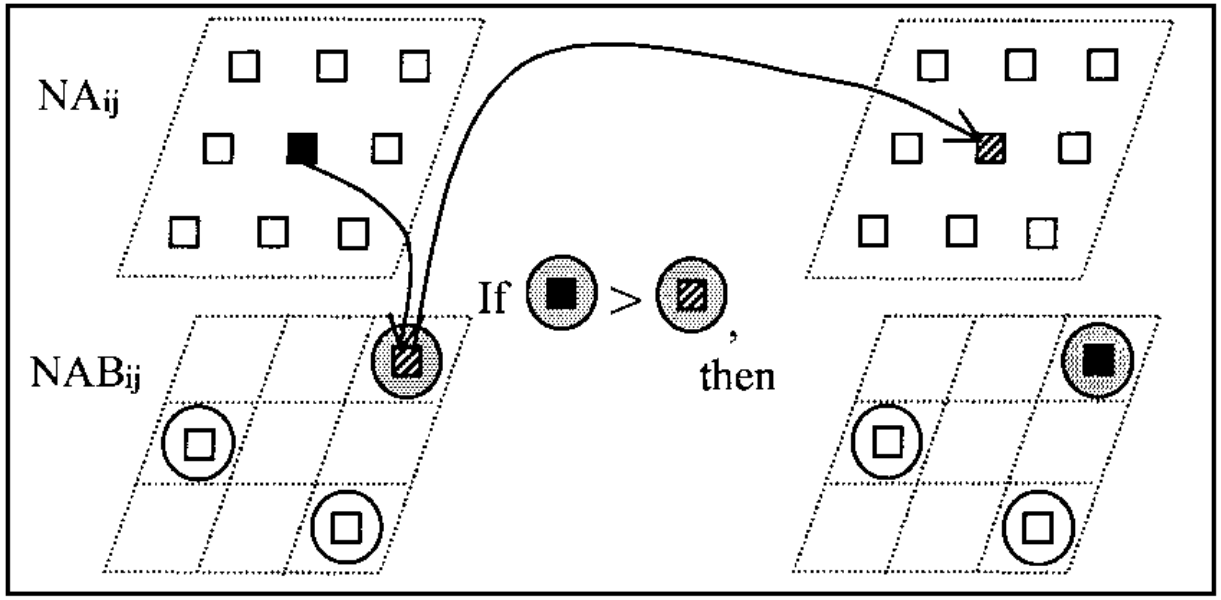
Kim *et al*. (2001)



(b) Competition between the existing endosymbiont and the potential endosymbiont.

Replacement – Pt 2

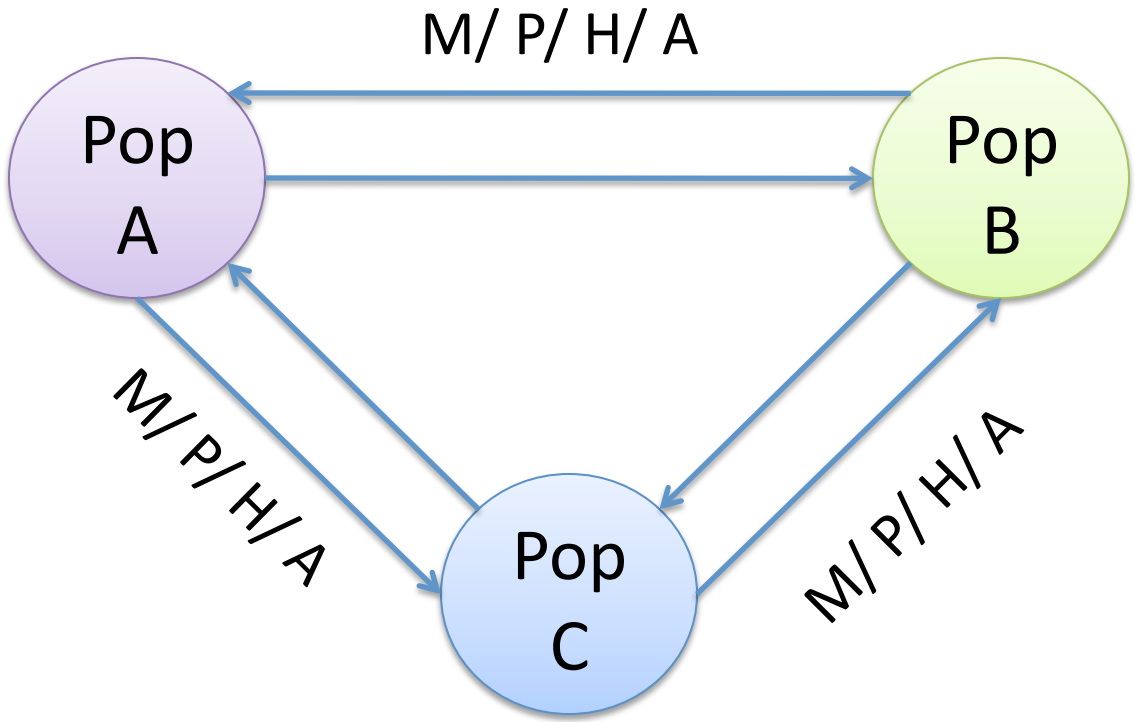
Kim *et al*. (2001)



(c) Competition of NA_{ij} with NAB_{ij}.

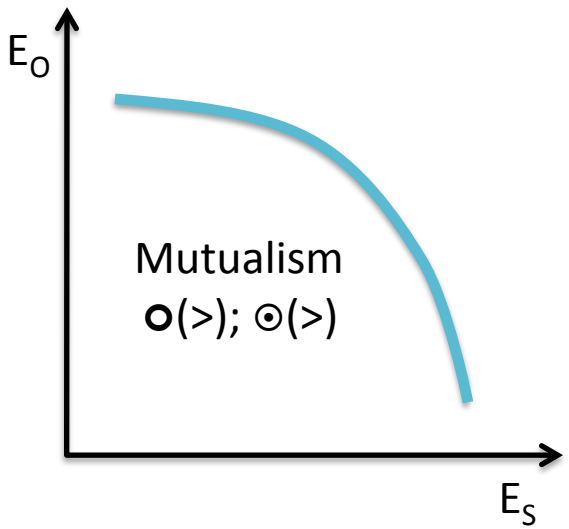
Example Symbiotic Models III: Coevolutionary Relations

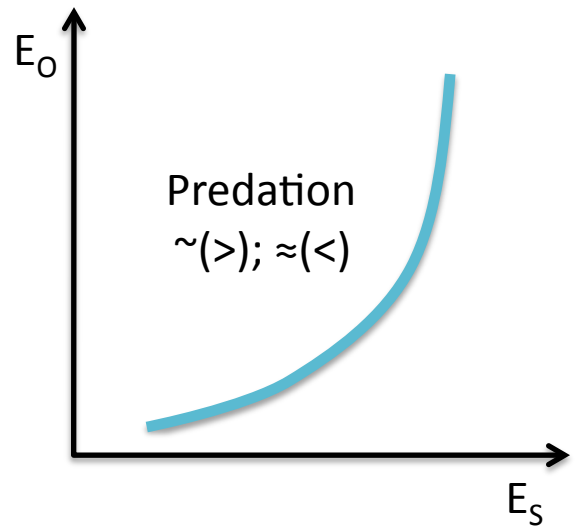
Symbiotic Pareto Evolution
(Eguchi *et al.* (2006))

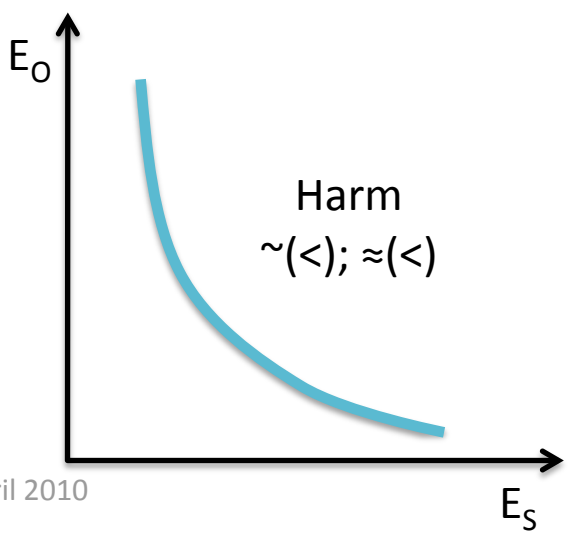


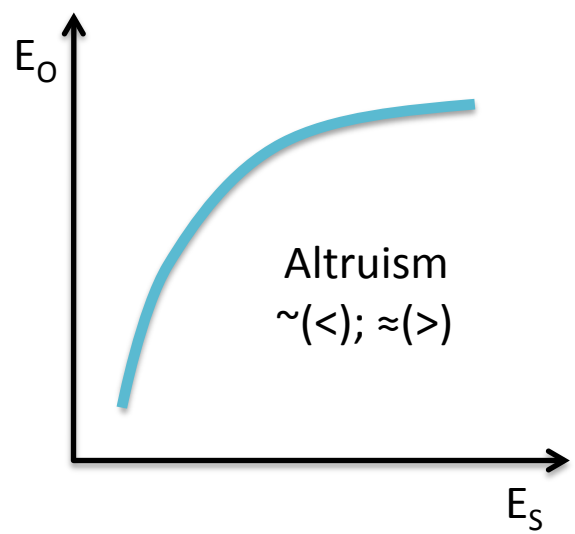
Symbiotic Pareto Evolution

(Eguchi *et al.* (2006))



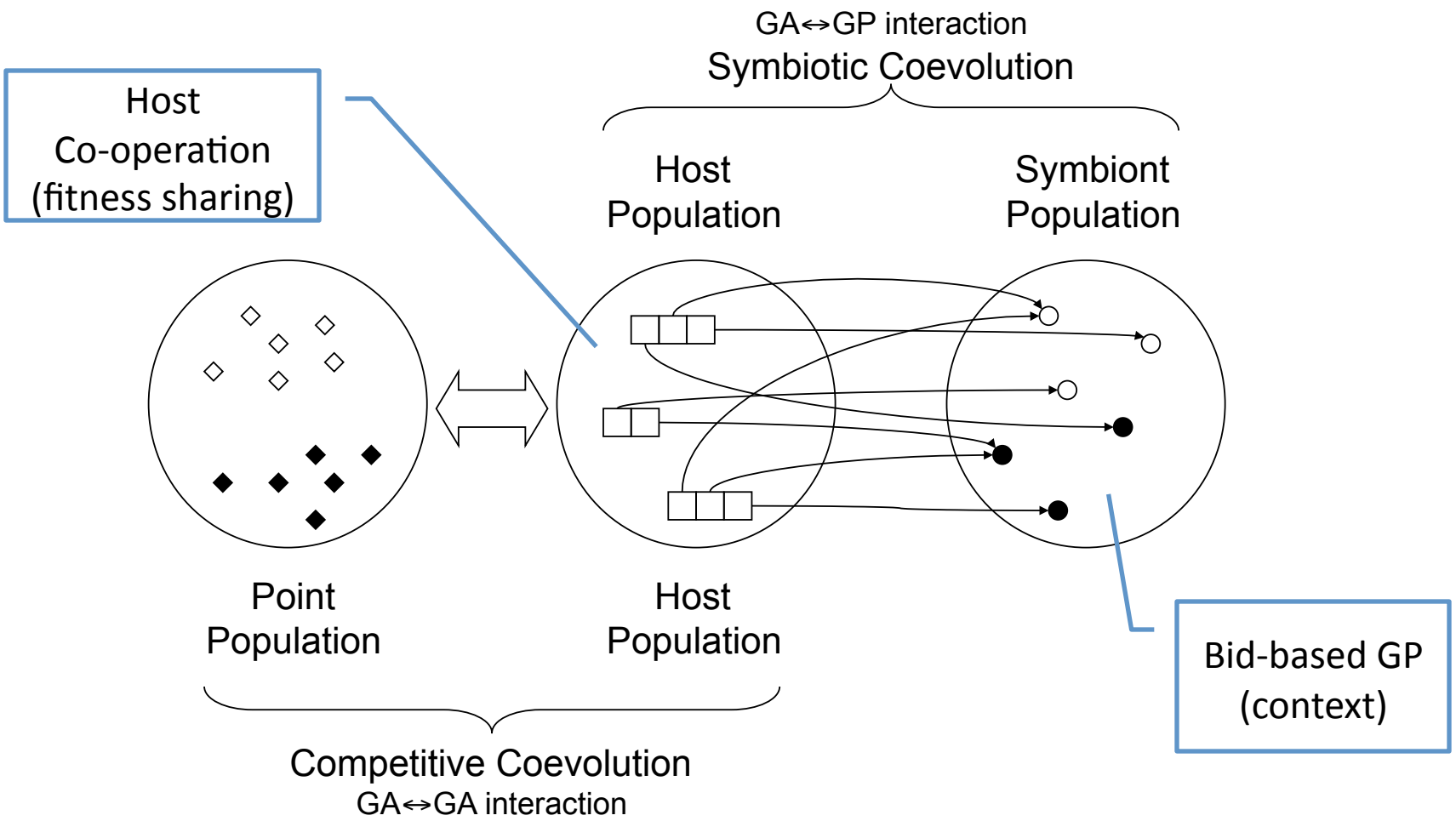




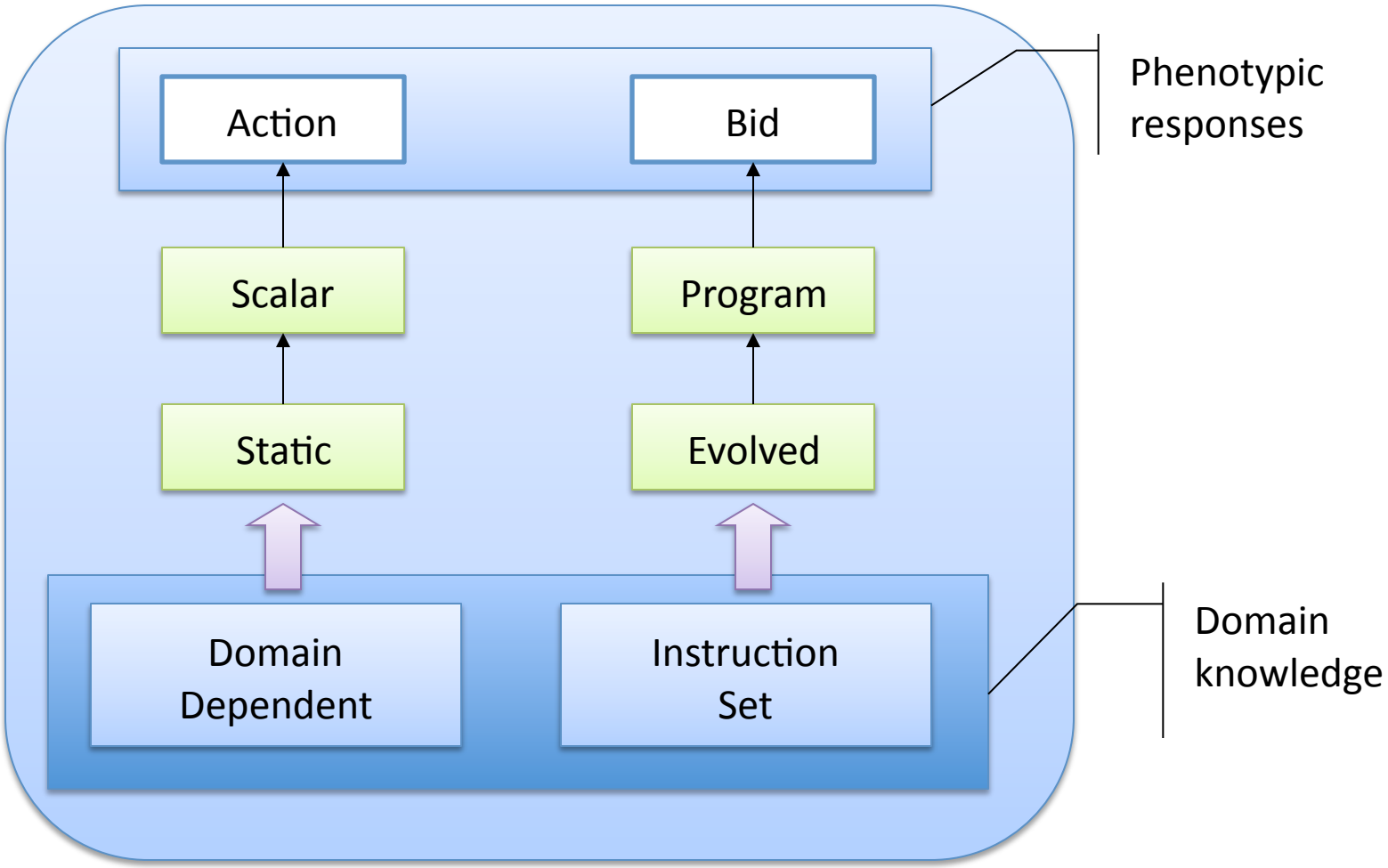


Example Symbiotic Models IV:
Metabolic Relations

Metabolic/ Spatial – GP:
Lichodzijewski and Heywood (2008)



Achieving Context – Bid-based GP:
Lichodzijewski and Heywood (2008)



Other Developments

- Learning Classifier Systems (Temporal)
  - Bull and Fogarty (1996), Tomlinson and Bull (2005), Baghshah et al. (2007)
- Host-Parasite Models (Spatial/ Genetic)
  - Daida et al. (1995), Wallin et al. (2005)
- Fuzzy Systems (Coevolutionary/ Genetic)
  - Hirasawa et al. (2000), Baghshah et al. (2007)
- Artificial Life

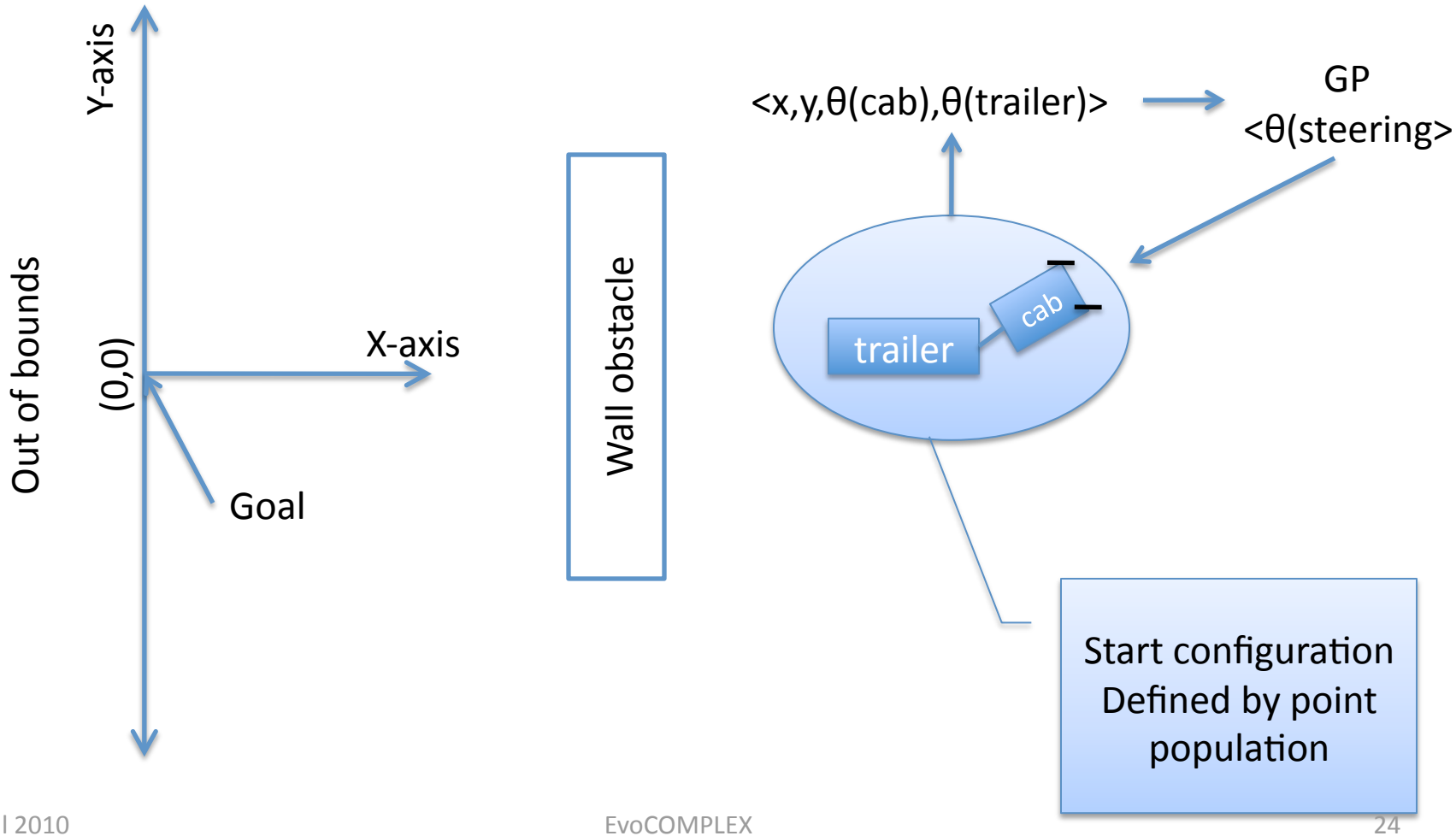
Discussion

- Context
  - Gene alignment
  - Explicit signaling/ communication
- Formulating fitness functions
  - Mechanism Design
    - Pareto formulations often too brittle in practice
- Layered Learning
  - Build ‘complex’ behaviors from ‘simple’ behaviors
- Contribution to other paradigms
  - Evolutionary NNs in general
  - Teaming in GP

Acknowledgements

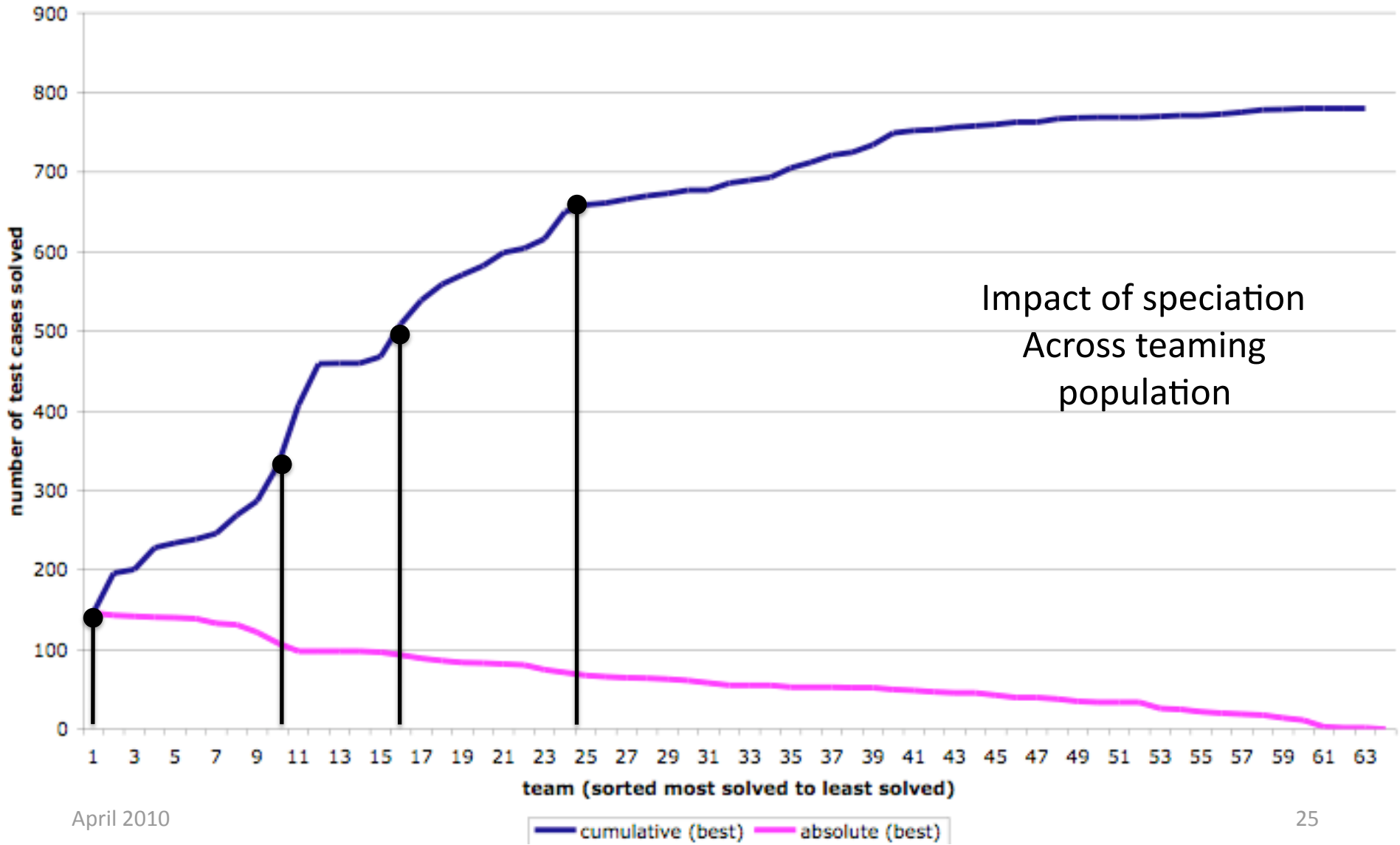
- NSERC
- MITACS
- Killam Scholarship program
- Anonymous reviewers

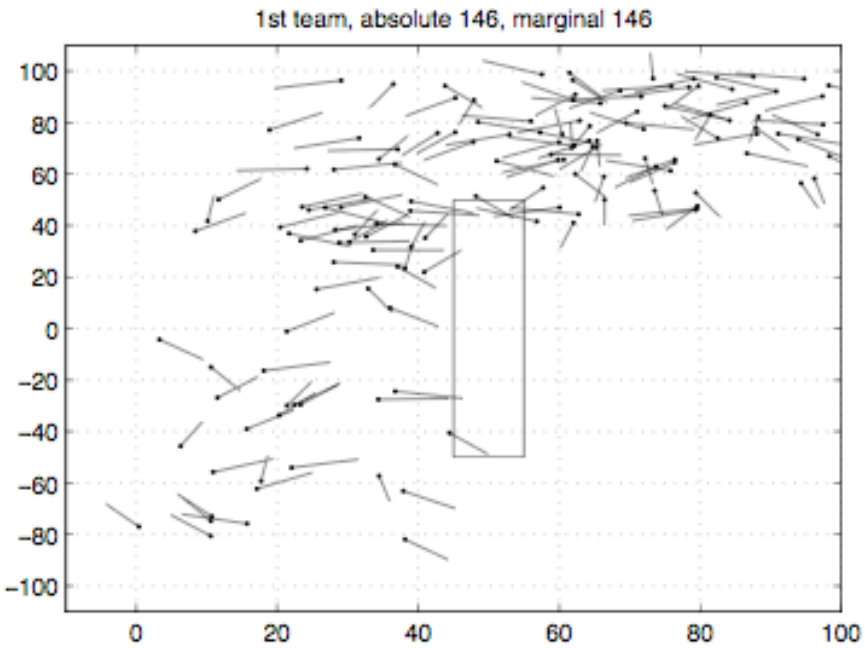
Hidden State Truck Backer-upper:
Lichodzijewski and Heywood (2009)

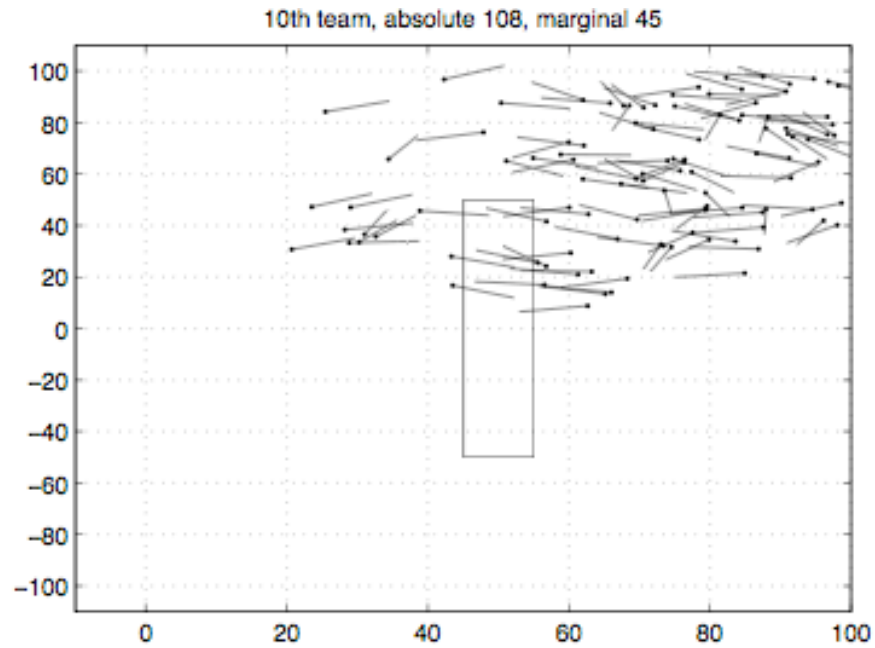


Hidden State Truck Backer-upper:

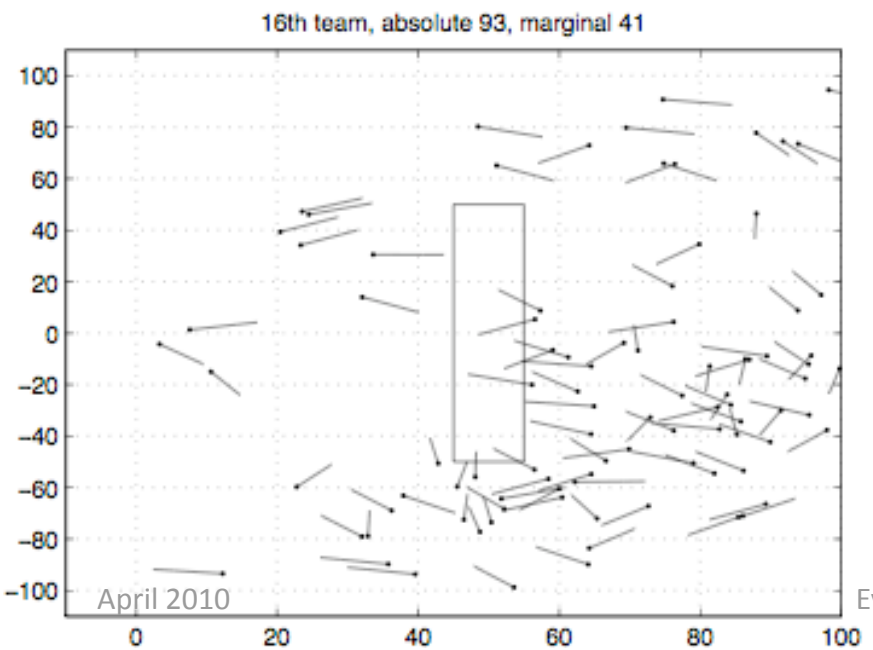
Case for layered learning

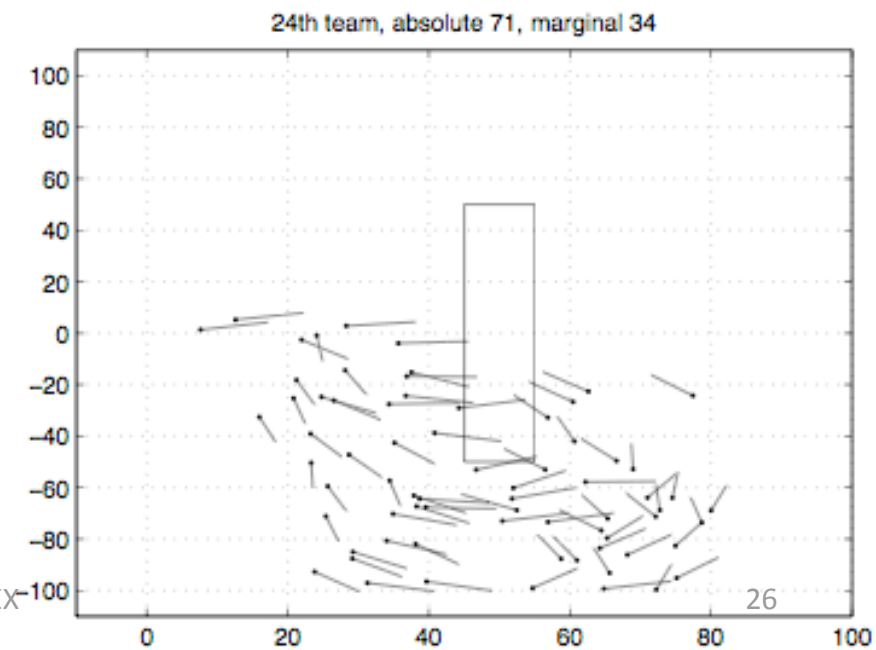






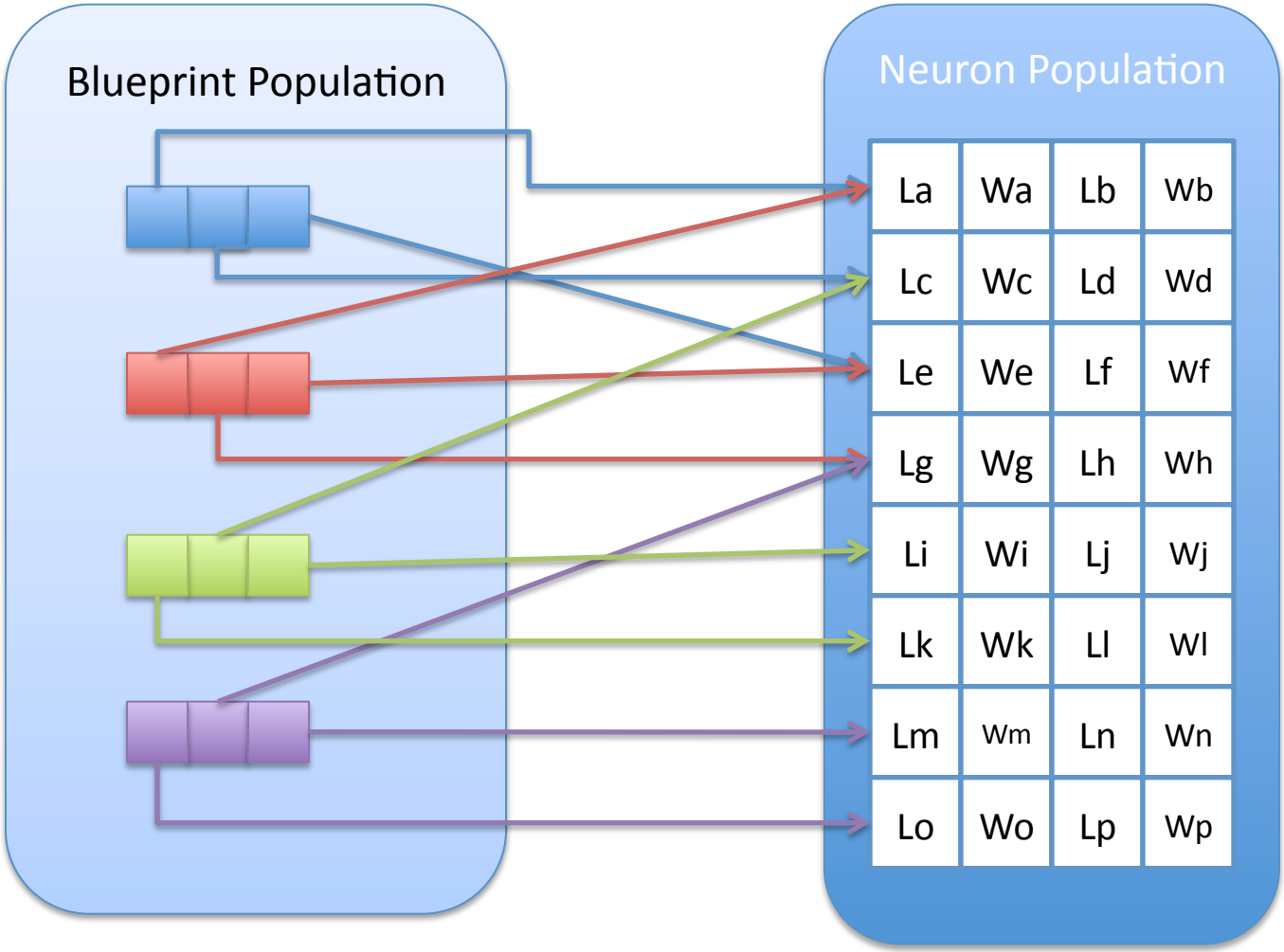
Case for layered Learning: Layer (i – 1) as actions for layer(i)



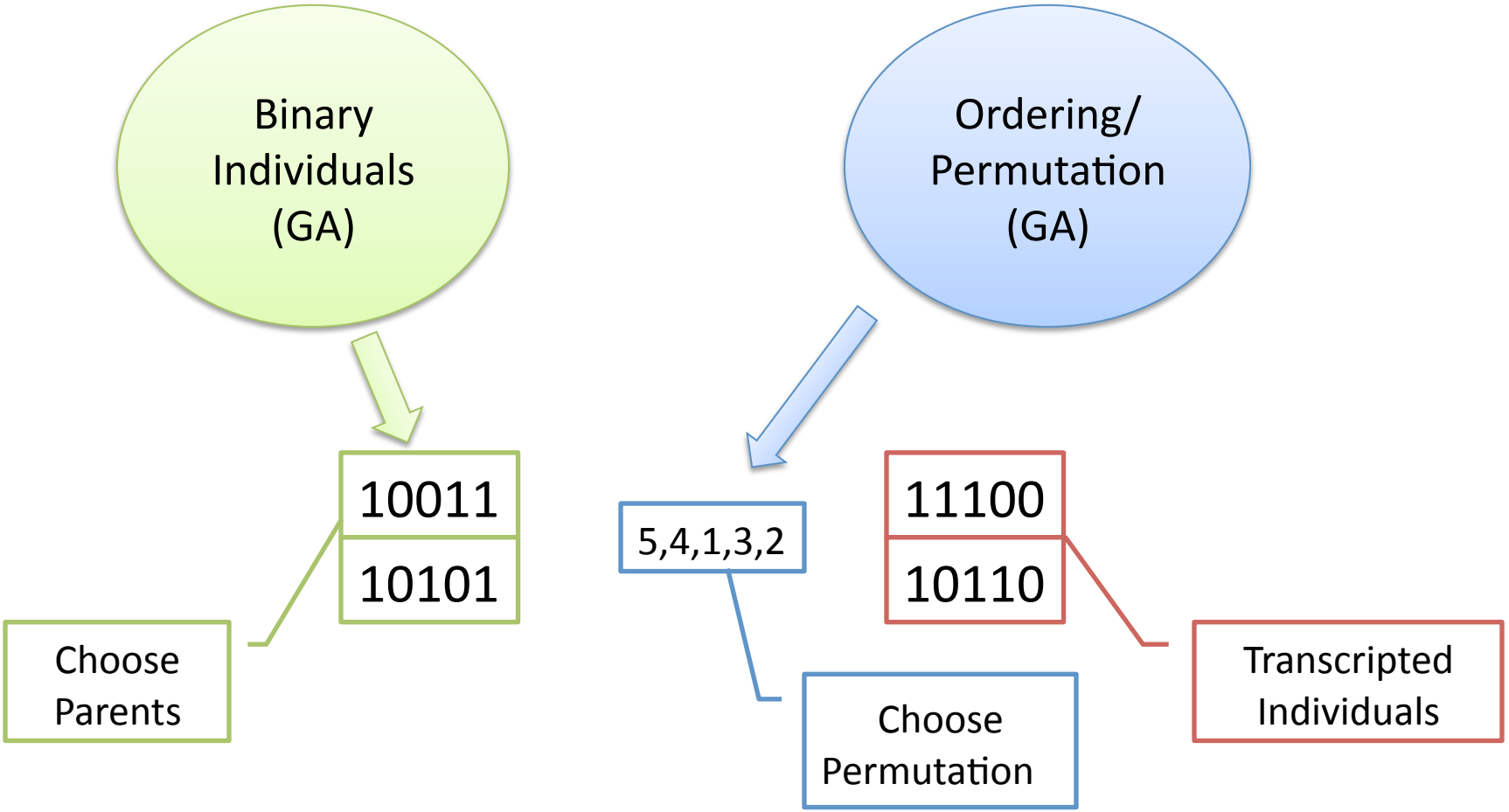


Multi-Population – Neural Networks:

Moriarty and Miikkulainen (1998)

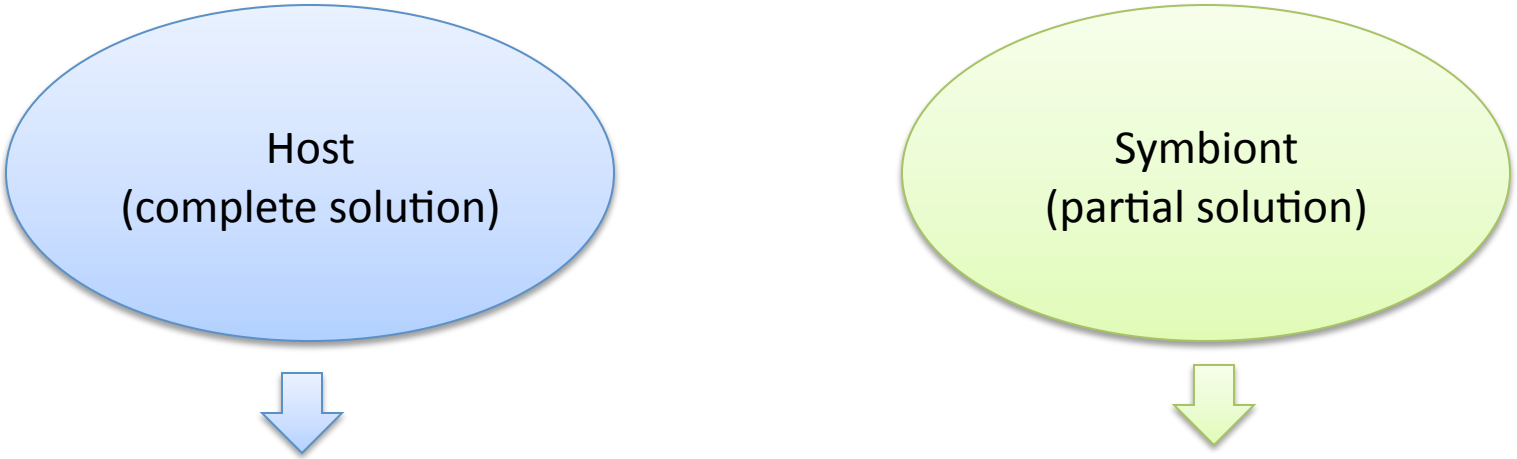


Multi-Population – Genetic Algorithms:
Paredis (1995)



Metabolic/ Genetic Relations:

Wallin *et al*. (2005)



Candidate host:
0 0 0 0 0 0 0 0

Candidate symbiont:
<3, 111>

Child following symbiosis: 0 0 0 1 1 1 0 0