Developing Methods to Design for Evolvability: Research Approach and Preliminary Design Principles

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Motivation

- Very few designs start from a “clean sheet”
- Designing an evolvable system may reduce the long term cost of system upgrades/replacements in the presence of context shifts
- Evolvable families of systems can potentially deliver more value in the face of changing contexts
- Implementing evolvability as a forethought in the design process may take advantage of future generational changes

Characterizing evolvability may allow designers to better understand how systems change between generations

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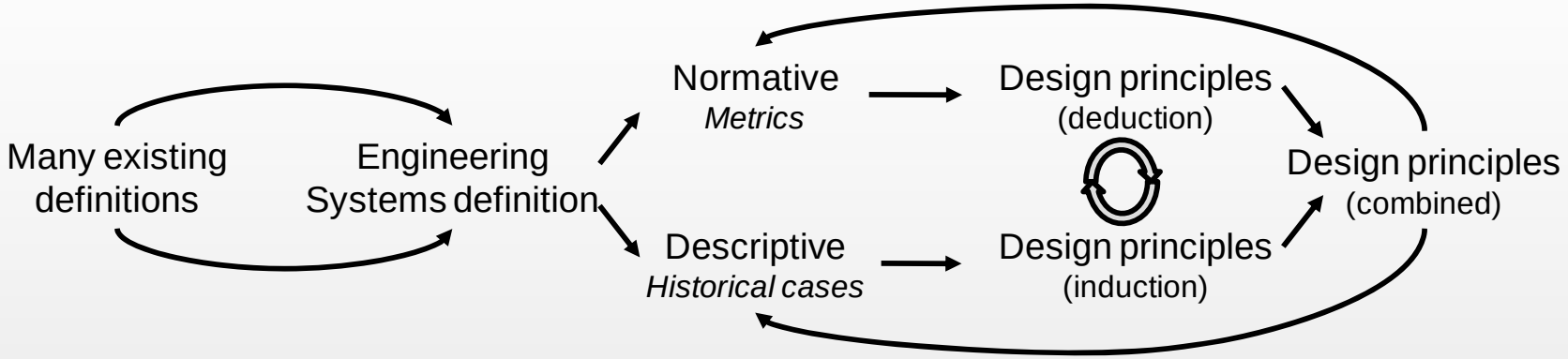
Research Approach



- Evolvability will be investigated using descriptive and normative approaches

The outcomes of this research will be: (1) a formal definition of evolvability, (2) a set of evolvability design principles, and (3) evolvability metric(s)

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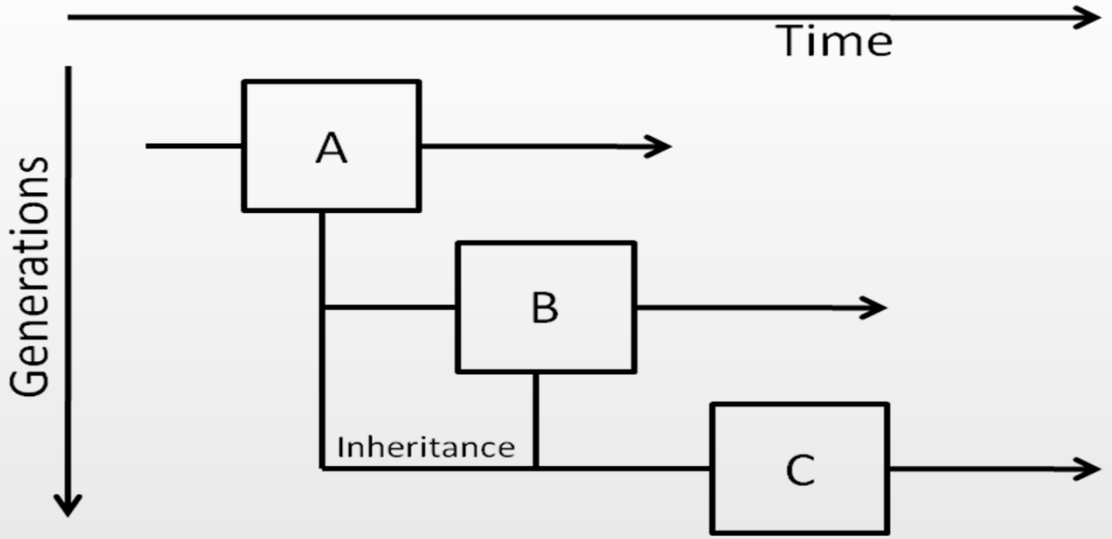
Evolvability Defined

The ability to change an inherited design across generations [over time].



- Key aspects
  - Some threshold amount of change occurs
  - Change occurs through some process of variation and selection
  - Redesign originates from inherited design(s)
- Based on definitions from biology, computer science, and engineering

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Recognizing Evolvability

In order to interpret through an "evolvability lens," here are some questions to ask:

- What are the generations?
  - Timescales, change threshold to define new "gen"
- What changes are occurring?
- What is driving the change?
- How are the changes implemented?
  - Inheritance, process
- What are the change costs?

These questions form the basis for analyzing case studies with respect to evolvability

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System Example

High Mobility Multi-purpose Wheeled Vehicle (HMMWV)

Mission: To provide a light tactical vehicle for command and control, special purpose shelter carriers, and special purpose weapons platforms throughout all areas of the modern battlefield.

"Since the Humvee was first fielded, the design of the vehicle has hardly stood still. Although to the casual observer, a vehicle coming off the assembly line today looks just like a vehicle that came off the line in 1985, there is hardly a nut and bolt on the vehicle that hasn't changed."

- Craig McNab, AM General Director of Communications

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Timescale Analysis

- Guiding questions:
  - How often will available technologies change?
  - How often will requirements change?
  - What is the system life cycle?
  - Is the system part of an SoS?
- Answering these questions can help designer decide when to incorporate evolvability
- Current research emphasis on planning generations based on frequency of changes e.g. “battle rhythm” (Dahmann et al. 2011)

The advantage gained by an evolvable system can vary based on the change timescales

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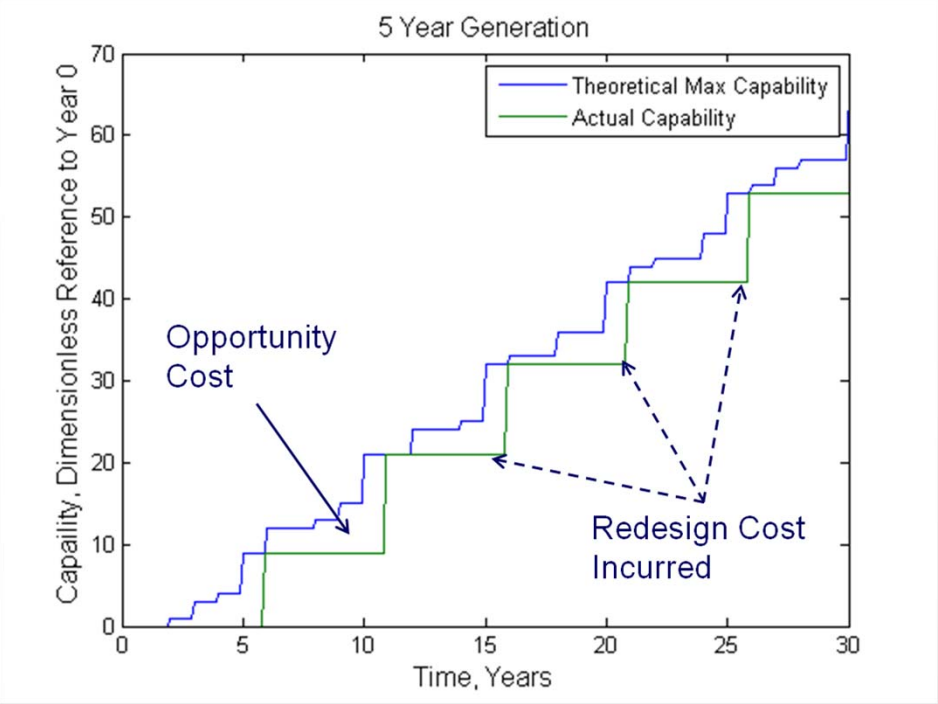
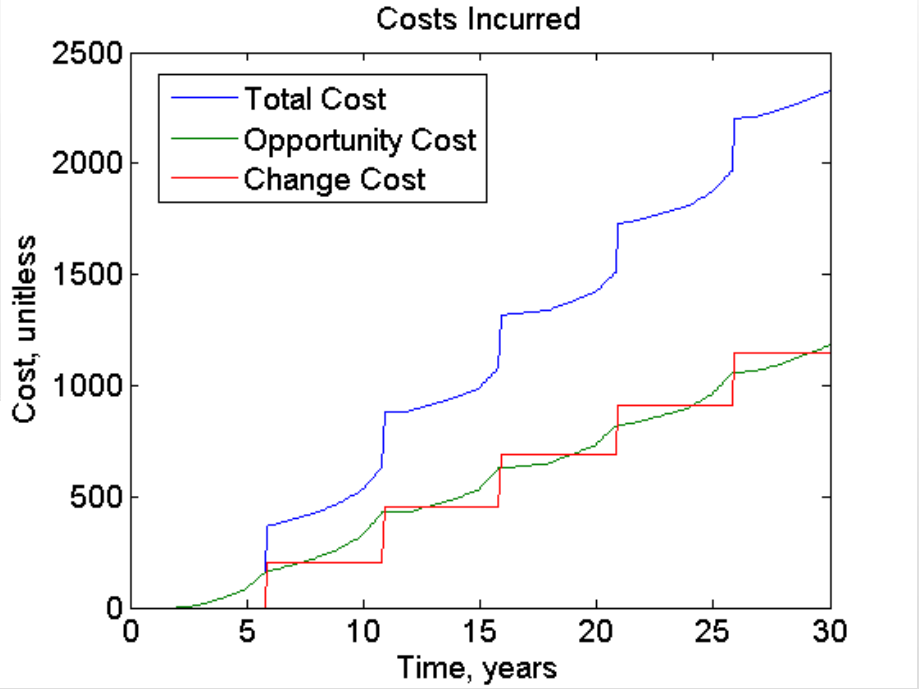
Technology Syncopation



Timing of generations drives the opportunity costs and the change costs



Opportunity cost and change costs are compared to the benefit of added capability

Properly planned generations may make more efficient use of changing technologies

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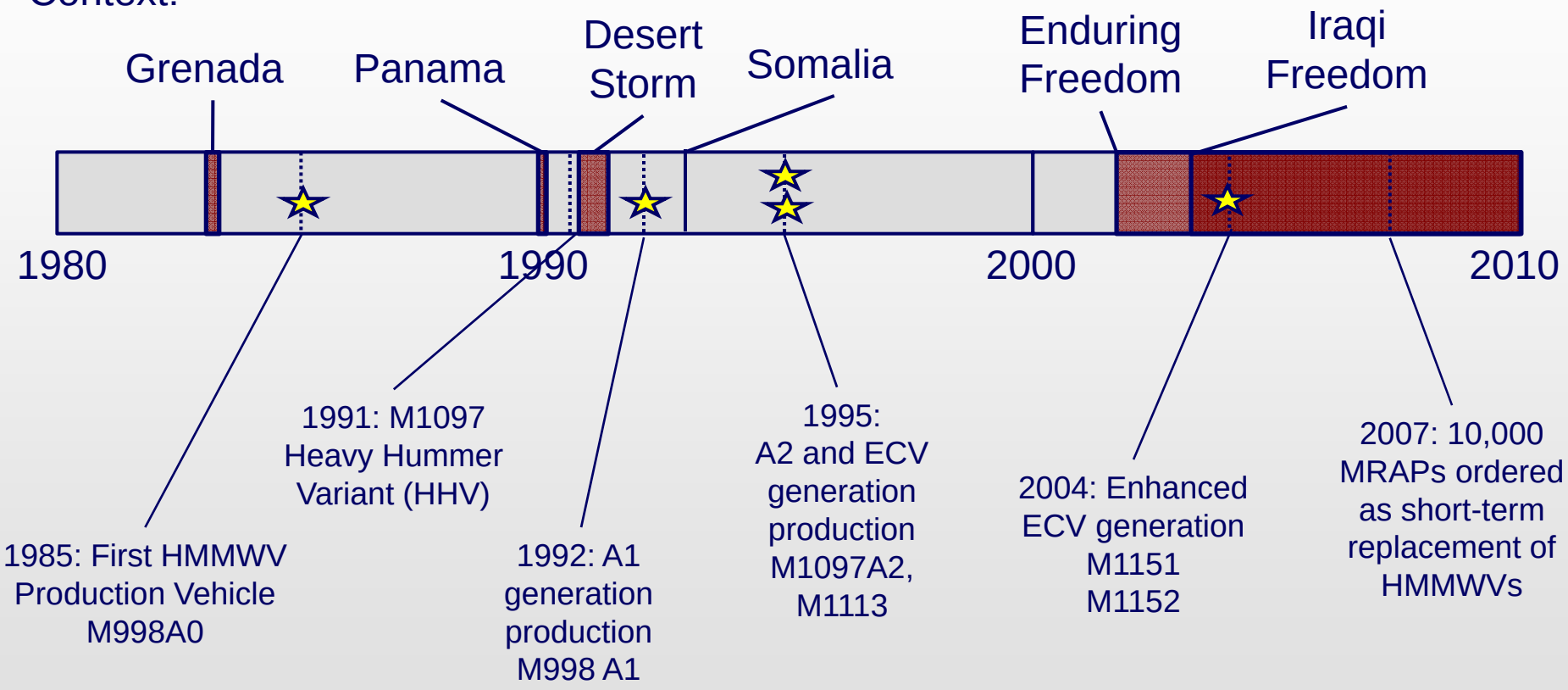
HMMWV Timeline

Context:



Generations range from 3 – 9 years and correspond to changing contexts (with delay)

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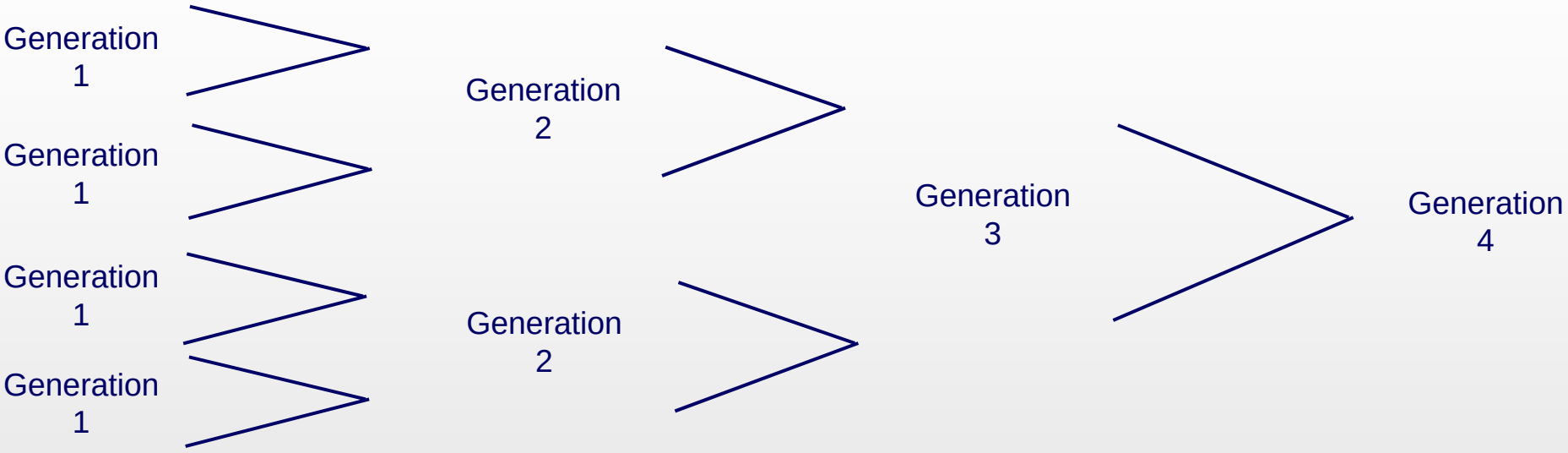
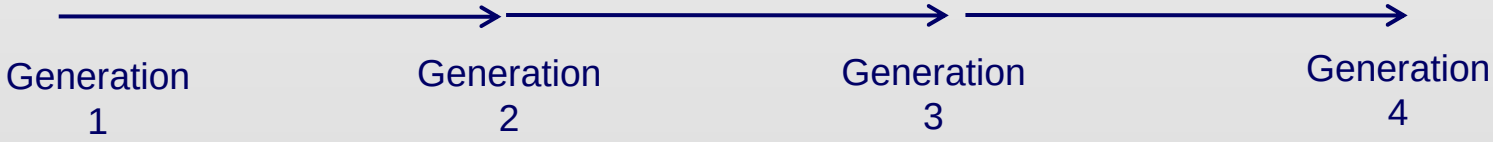
Biological Inheritance



Overall Species:



Inheritance comes from parent generation

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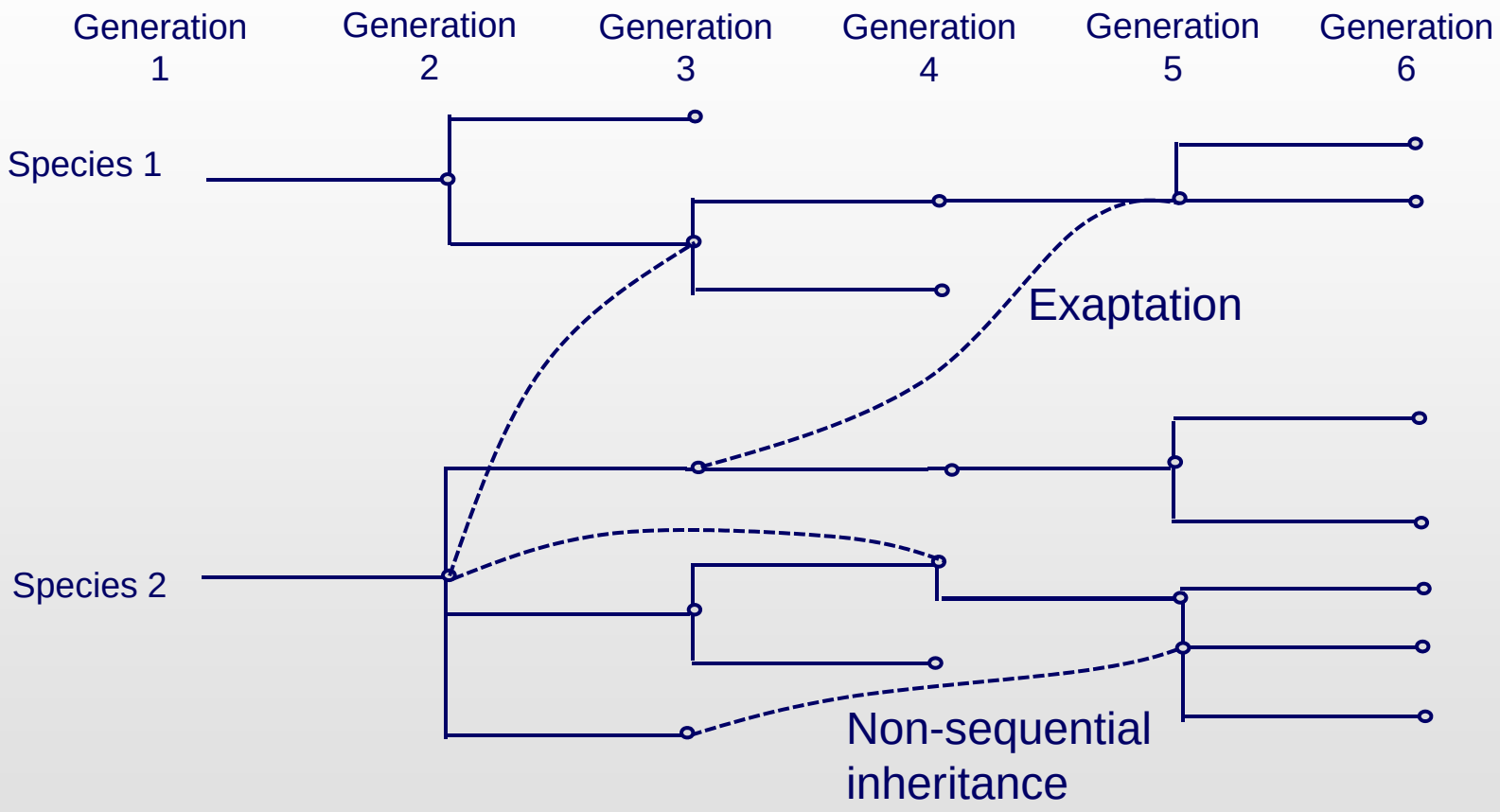
Technological Inheritance



Inheritance can occur from different “species” and different “generations”
Successful ideas can be shared across time and domains

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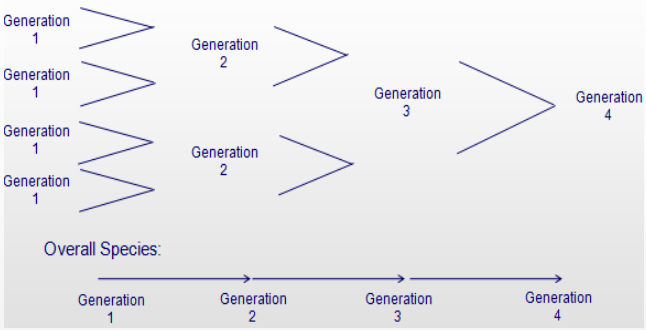
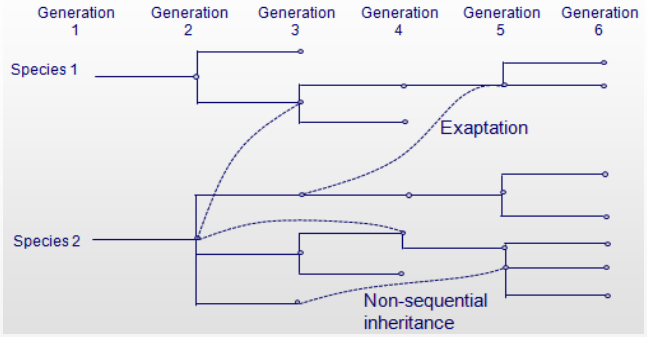
Bio & Tech Evolution





	Biology	Technology
Inheritance	Derived solely from prior generation (parents)	Derived from any prior generation (non-sequential)
Level of change	Slower and smaller incremental steps	Fewer, but larger steps between generations
Mechanism	Random variation through mutation/sexual reproduction	“Intelligent Designer”
Exaptation	Rare inadvertent improvements	Common between separate domains and systems

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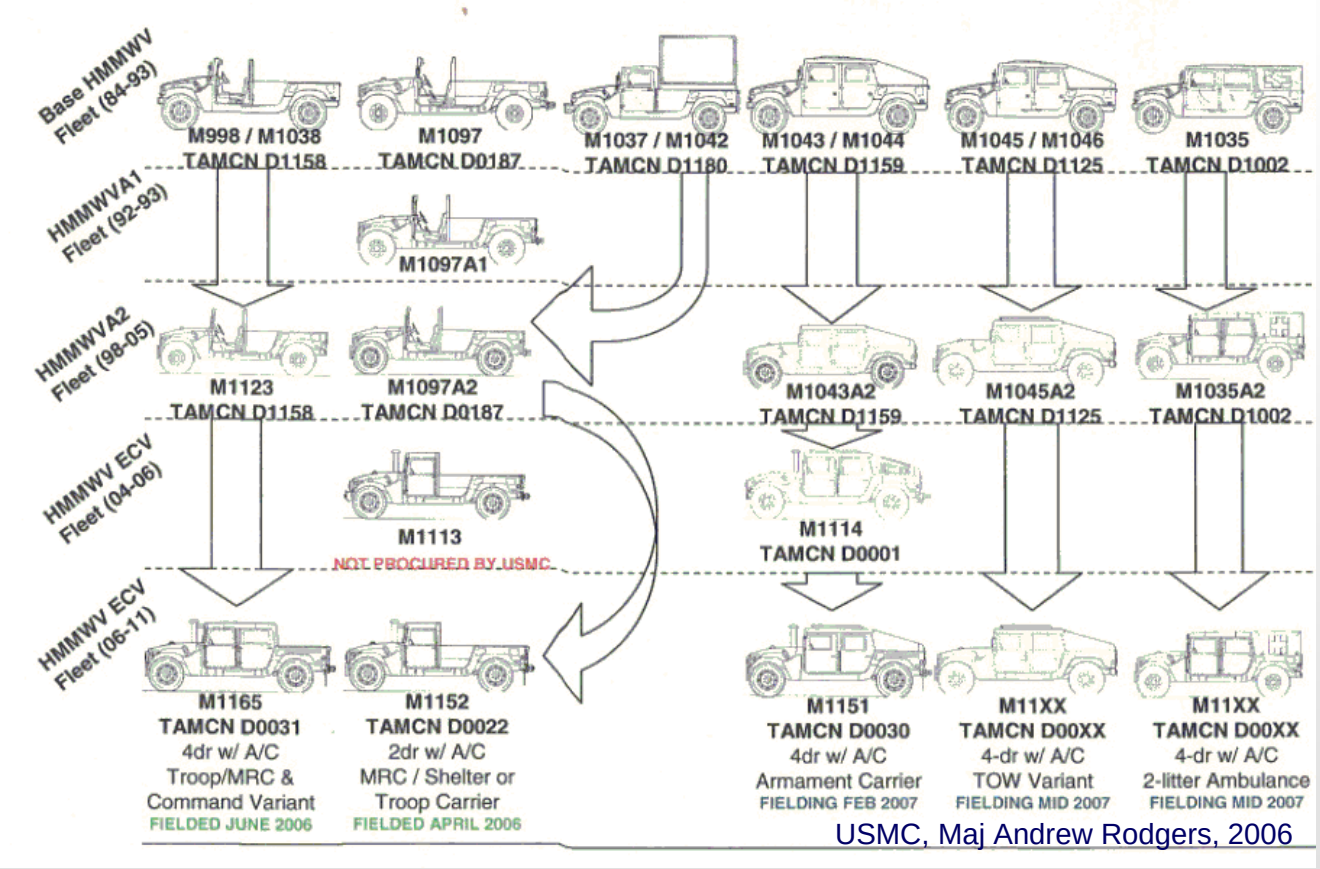
HMMWV

Four main generations of the HMMWV:

- **A0 (1985)**
- **A1 (1992)**
- **A2 (1995)**
- **ECV (1995)**
- ***Enhanced ECV (2004)***



USMC, Maj Andrew Rodgers, 2006

- **Expanded-Capacity Vehicles (ECV) have been upgraded with new models and kits throughout the 2000's**

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HMMWV

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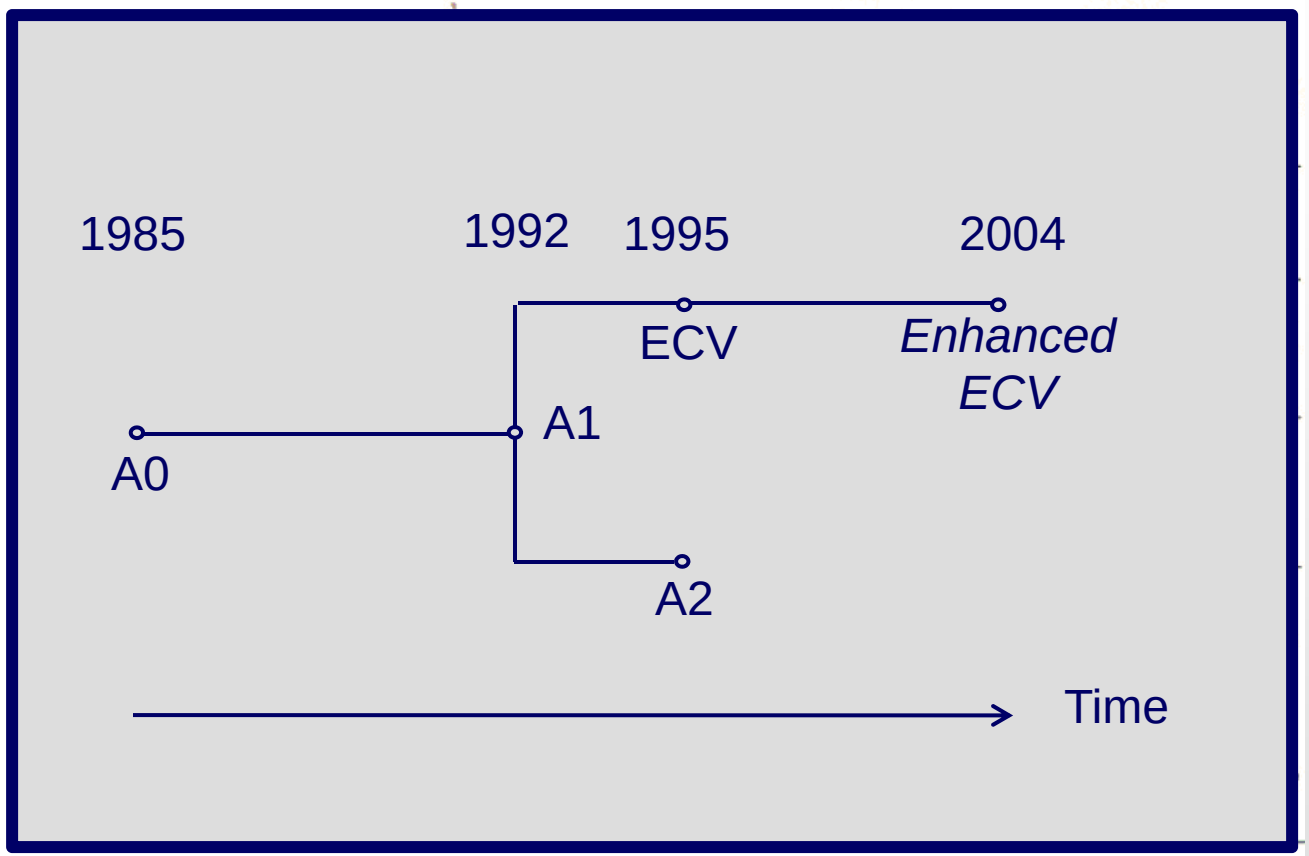

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Parameter Changes Across Generations

	A0	A1	A2	ECV
Engine	6.2L Diesel 3 speed	6.2L Diesel 3 speed	6.5L Diesel 4 speed	6.5L Turbo Diesel 4 speed
GVW	7,700 lb.	10,000 lb.	10,300 lb.	11,500 lb. up to 16,500 lb.
Payload	2,500 - 3,600 lb.	2,500 - 3,600 lb.	3,500 - 4,400 lb.	1,800 - 5,100 lb.
Other		Improved suspension, drivetrain, seats, brakes	Improved emissions, capacity, heater, steering column	Improved suspension, armored and un-armored, air conditioning

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Armor Requirement Shifts

Field training/ light tactical usage

M988 military Humvee created

Small arms fire, ambush, urban warfare

Side armor
Bullet resistant glass
Bigger engine
Better suspension

Simple IEDs and ambush

Increased Armor
Better suspension
Improved Brakes
New Tactics

Advanced IEDs/mines

Even more armor, including under-carriage
MRAP developed with 'V' shape

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HMMWV Next Steps

Questions to be explored and further researched:

- What was AM General's redesign process? Was it evolutionary?
- How difficult were the changes to implement?
  - How long? At what cost?
- What changes were inspired by in-field alterations?
  - "Hillbilly armor"
- Can we extract evolvability design principles from AM General's design methods and considerations?

Analysis across case studies will lead to evolvability design principles

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Preliminary Design Principles

Initial investigation has examined design principles seen in literature that could enhance evolvability

Principle	Implications for Evolvability
Targeted Modularity	Limits change propagation (Hansen 2003) (Holtta-Otto 2005)
Integrability	Compatibility and common interfaces (Fricke and Schulz 2005)
Scalability	Of a parameter or entire system (Fricke and Schulz 2005)
Decentralization	Distributed resources to limit effect of changes (Fricke and Schulz 2005)
Redundancy	Gives flexibility to designer to eliminate components(Fricke and Schulz 2005)
Architecture changeability	Provides reduced cost and options for changes across generations (Ross 2006)
Reconfigurability	Self similar parts and maximizing information reconfiguration (Siddiqi and de Weck 2008)

Design principles will be validated using case studies and simulation with evolvability metrics

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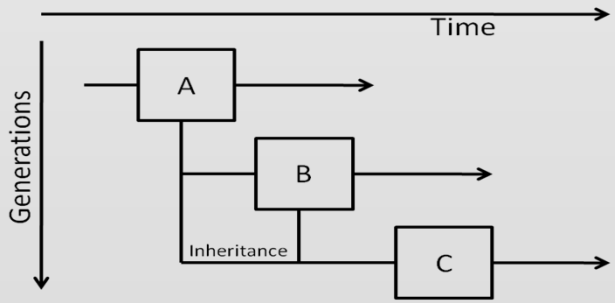
Conclusions

- Evolvability describes ability of a design to be modified across generations in the presence of changing contexts
- Evolvability potentially allows for more value to be delivered over a family of systems' lifetimes



Future Work

- Examine more case studies through research and interviews
- Expand and refine design principle set
- Develop metrics for measuring evolvability

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BACKUP SLIDES

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Measuring Evolvability

- A good metric should:
  - Capture each component of our definition
  - Be quantitative and unambiguous
  - Operate in as simple of a framework as possible
- Some leads from literature
  - Interface Complexity Metric
  - Ontological Approach (Evolvability)
  - Visibility Matrix (Change Propagation)
  - Filtered Outdegree (Changeability)

Metrics for other ilities serve as a starting point for evolvability metrics.

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