On the Design of Rapidly Deployable Field Robotic Systems

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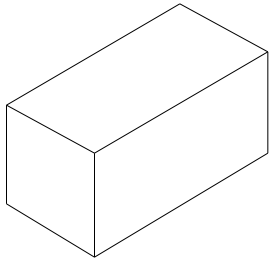
Modular Concept

Inventory



Power Module

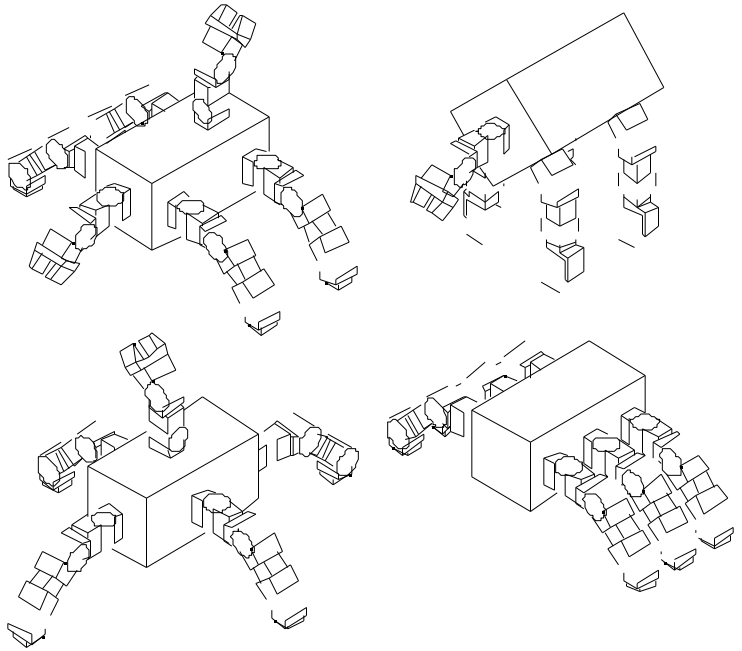
Joints

Connecting Links

End Effectors

move limb 1 forward	move limb 2 forward
grasp object	retrive sample
move body forward	communicate with ground station

Action Modules



Robot Assemblies

move limb 1 forward

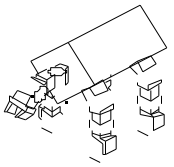
move body forward

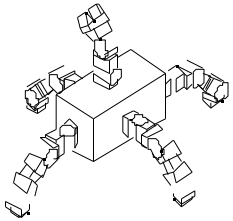
move limb 2 forward

retrive sample

Action Plan

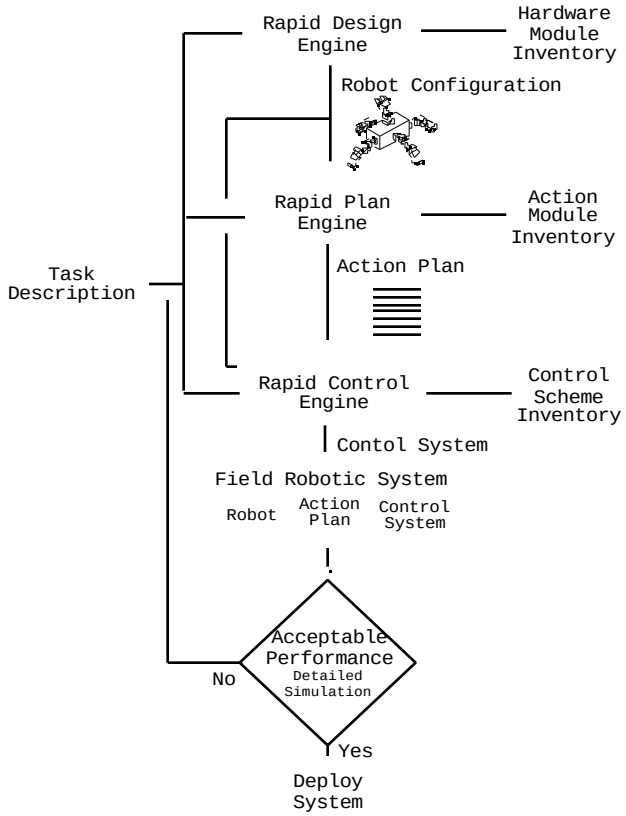
Advantages of Modular Design



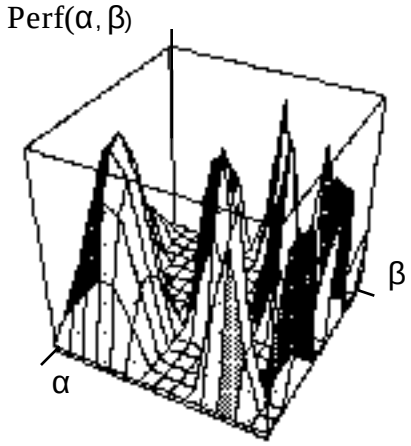


- Rapidly Deployable
  - Pre-existing Inventory
- Cost Effective
  - Multiple Missions = One Inventory

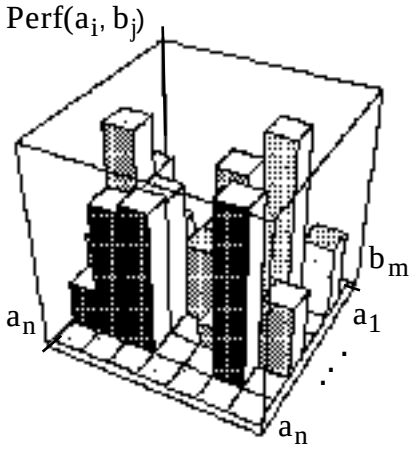
An Automated Modular System



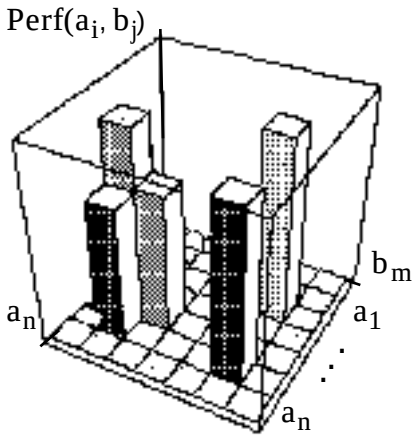
Various Design Spaces



Continuous Design Space

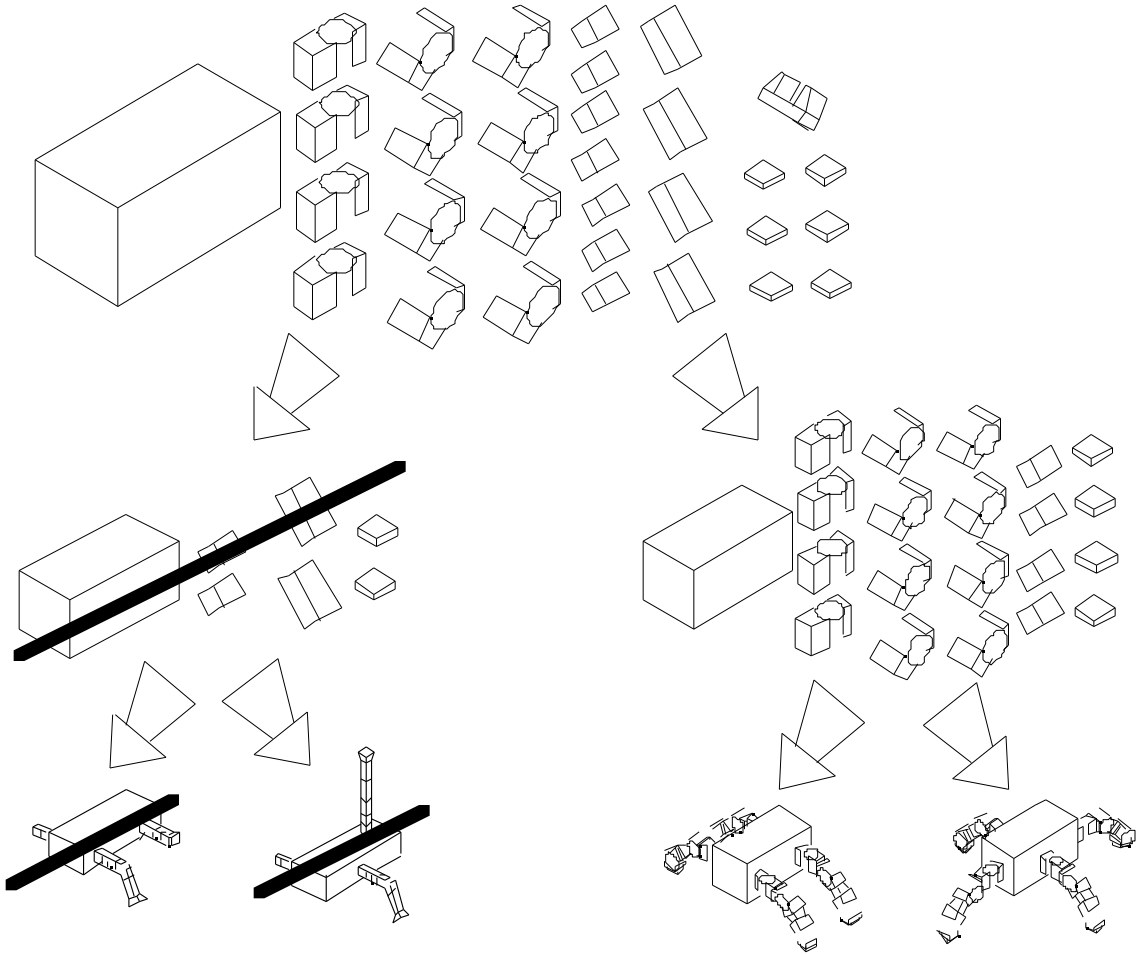


Discrete Design Space



Reduced Design Space

Hierarchical Selection Process



Modular Design Procedure

Basic Hypotheses of a Modular Approach

1. A reasonable size inventory of components can provide reasonably useful robots for a reasonable number of applications.

2. Simple tests, based on a fundamental understanding of the physics of these systems, can be used, in a hierarchical manner, to distinguish between good and bad robot designs for a given application.

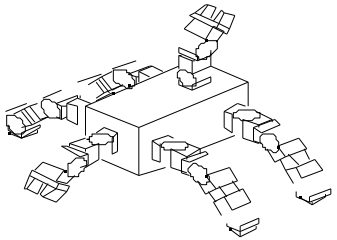
3. A robot can be designed without precise knowledge of its action plan (how the robot will be used).

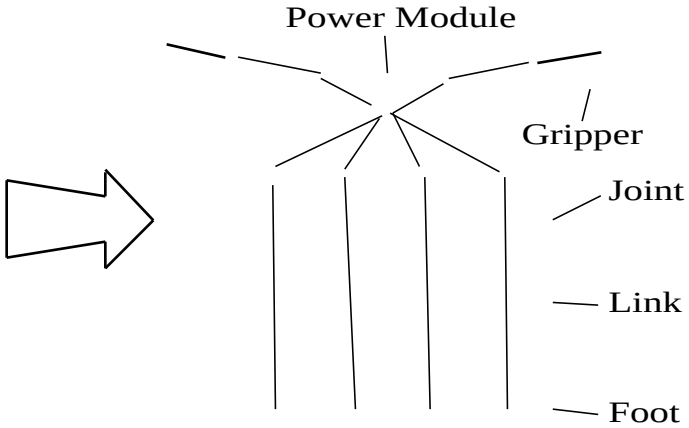
Physics Based Evaluation Tests

Kit Evaluation
- cost
- weight
- etc.

Genetic Algorithms in Robot Configuration Synthesis

- Modular systems have a natural mapping into the GA framework



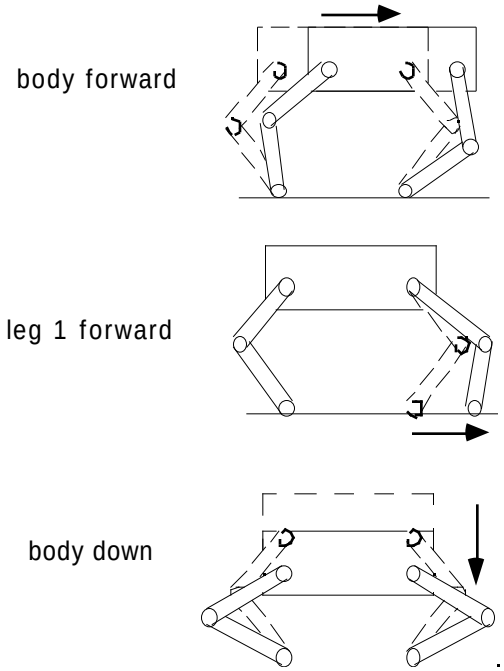


Robot Assembly

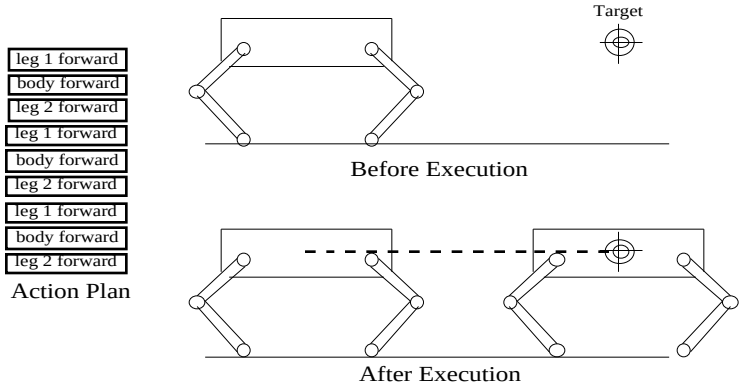
Tree Chromosome Representation

- Crossover and mutation operators evolve good robot assemblies
- Fitness of derived from fundamental physics of task

Rapid Planning Procedure

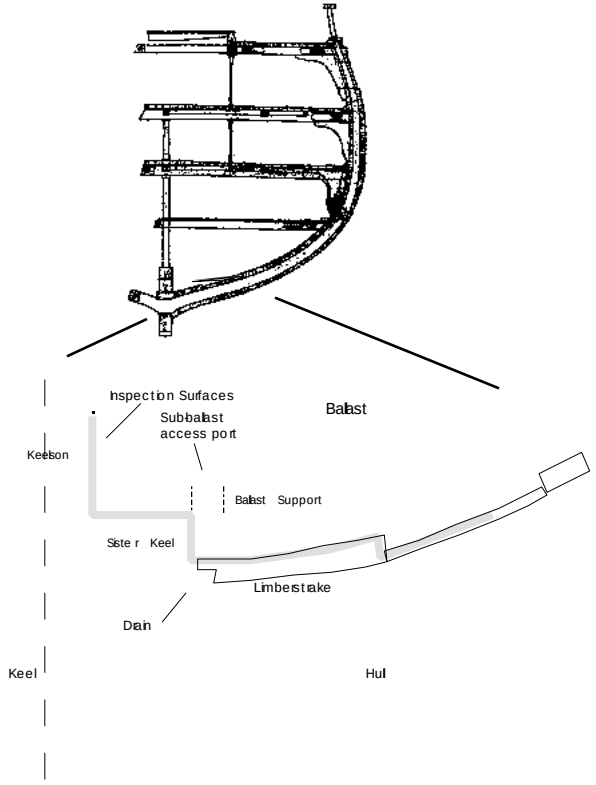


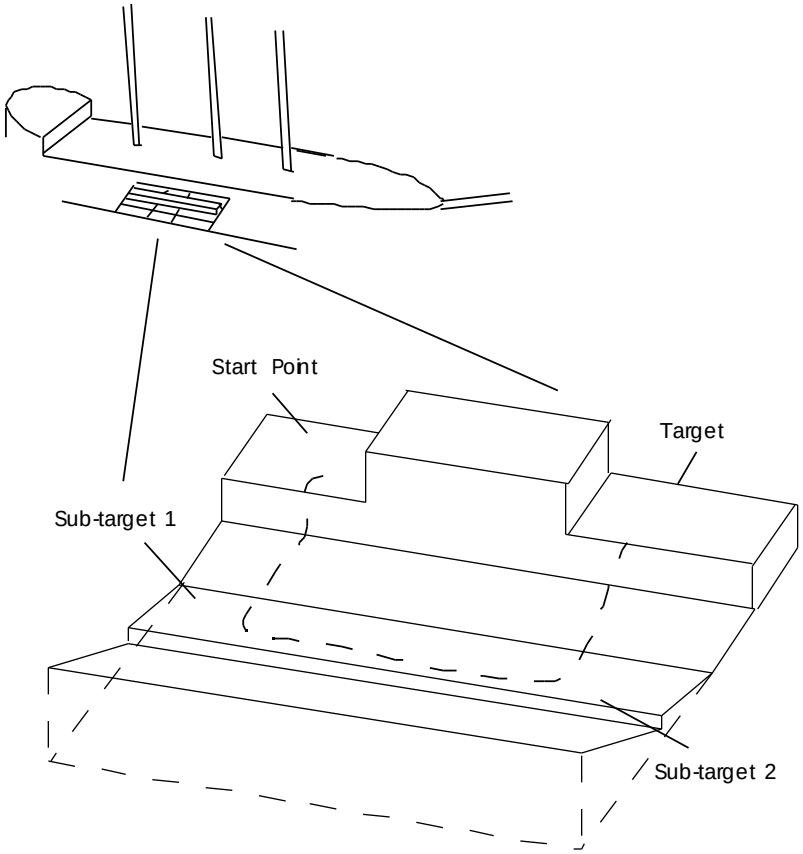
Software Action Modules



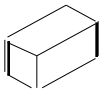
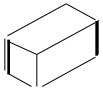
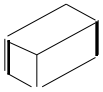
Action Scripts

U.S.S. Constitution Sub-Ballast Inspection Task





A Module Inventory

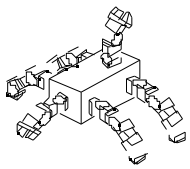
	Quantity	ID #	Type	Mass (oz.)	Dimension (in.)	Cost ($)	Notes
	1	101	Electric Power/Control	48	8 x 4 x 4	3000	14 Attach Ports 5 W-hr. control 24 joints
	1	102	Electric Power	16	4 x 4 x4	100	5 Attach Points 5 W-hr
	1	103	Pneumatic Power/Control	256	24 x 9 x 9	5000	16 Attach Points 100 W-hr
	12	201	Electric Joint	4	2.5 x 1.5 x 1	300	100 oz.-in. torque
	12	202	Electric Joint	4.5	3.0 x 1.5 x 1	300	150 oz.-in. torque
	12	203	Pneumatic Joint	5	2.5 x 2.0 x 1.5	250	300 oz.-in. torque
	12	204	Pneumatic Joint	6	3.0 x 2.0 x 1.5	280	500 oz.-in. torque
	4	205	Axial Joint	4	2.0 x 1.5 x 1.5	200	50 oz.-in. torque
	8	301	Connecting Link	0.5	1 x 1 x 1	10	
	4	302	Connecting Link	1.5	2 x 1 x 1	10	
	1	401	Electric Gripper	4	1.5 x 1 x 2	200	20 oz. grip
	1	402	Pneumatic Gripper	4	2 x 2 x 3	225	10 lbf grip
	6	403	Foot	0.5	.5 x 1 x 1	20	contact sensor
	4	404	Electric Wheel	8	3 x 2 x 1.5	250	100 oz.-in. torque

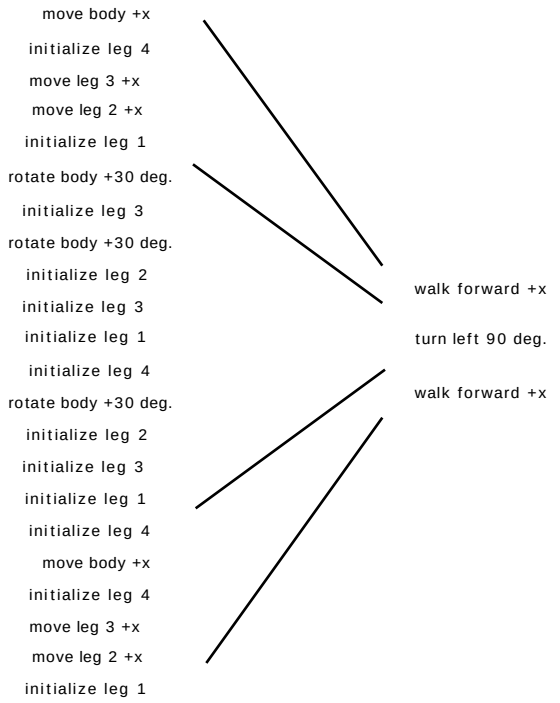
Results of Design Search

Results of Robot Designs in Constitution Task

	Design Search Fitness	Plan Used	Result	Power Consumed
Robot I	18.1	Simple Plan	Unsuccessful	-----
		GA Plan	Successful	647
Robot II	17.4	Simple Plan	Successful	744
		GA Plan	Successful	730
Robot III	17.1	Simple Plan	Successful	1119
		GA Plan	Successful	1037

Low / High Level Action Plans : A Local Navigation Task



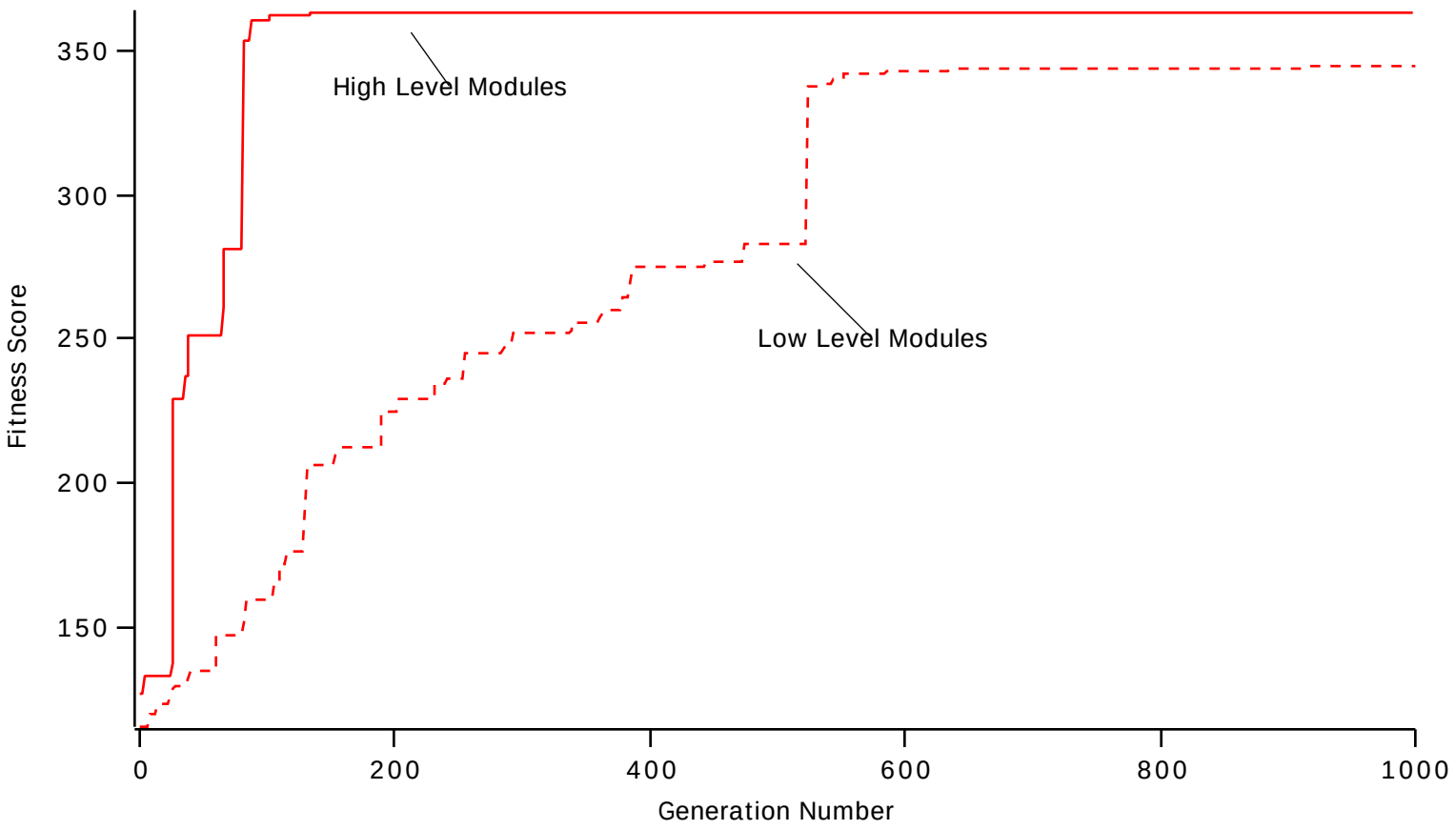


Local Navigation Task

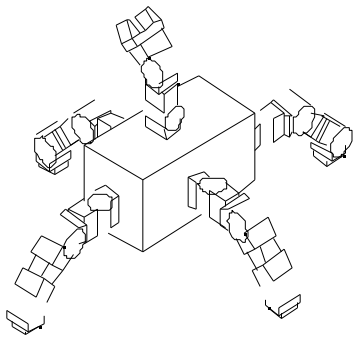
Low Level Action Plan

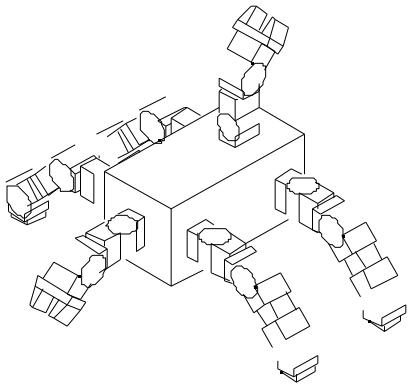
High Level Action Plan

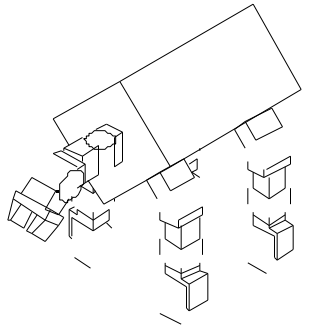
Convergence Results

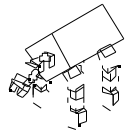


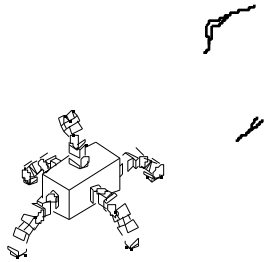
A Result = 3 Robots : 3 Tasks : One Inventory

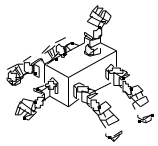












Conclusions

- A Modular Design Approach will effectively reduce development time and cost.
- Small changes in robot configuration can produce large changes in robot performance.
- Hierarchical Selection Process, based on a sound understanding of the physics of the system, can effectively produce good robot designs and robot action plans.

Future Work

- Evaluation of limits of validity of basic hypotheses

Continued Development of Design Methodology

- Methods to select a Module Inventory for a given class of tasks.
- Introduction of sub-assemblies into both planning and design inventories.
- Exploitation of Designer's experience in search

- Development of a modular Control methodology

- Development of laboratory demonstration system