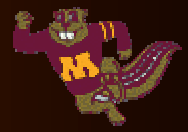
# Novel Gaits for a Novel Crawling/Grasping Mechanism



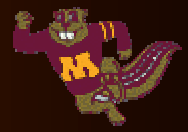
**Richard Voyles**

**Department of Computer Science and Engineering**

**University of Minnesota**

**AMAM 2000**

# Outline



- **Motivation**
  - **DARPA Distributed Robotics Program**
  - **Rangers and Scouts**
- **Design Details**
  - **Limb Mechanism**
  - **Integral Force/Torque Sensors**
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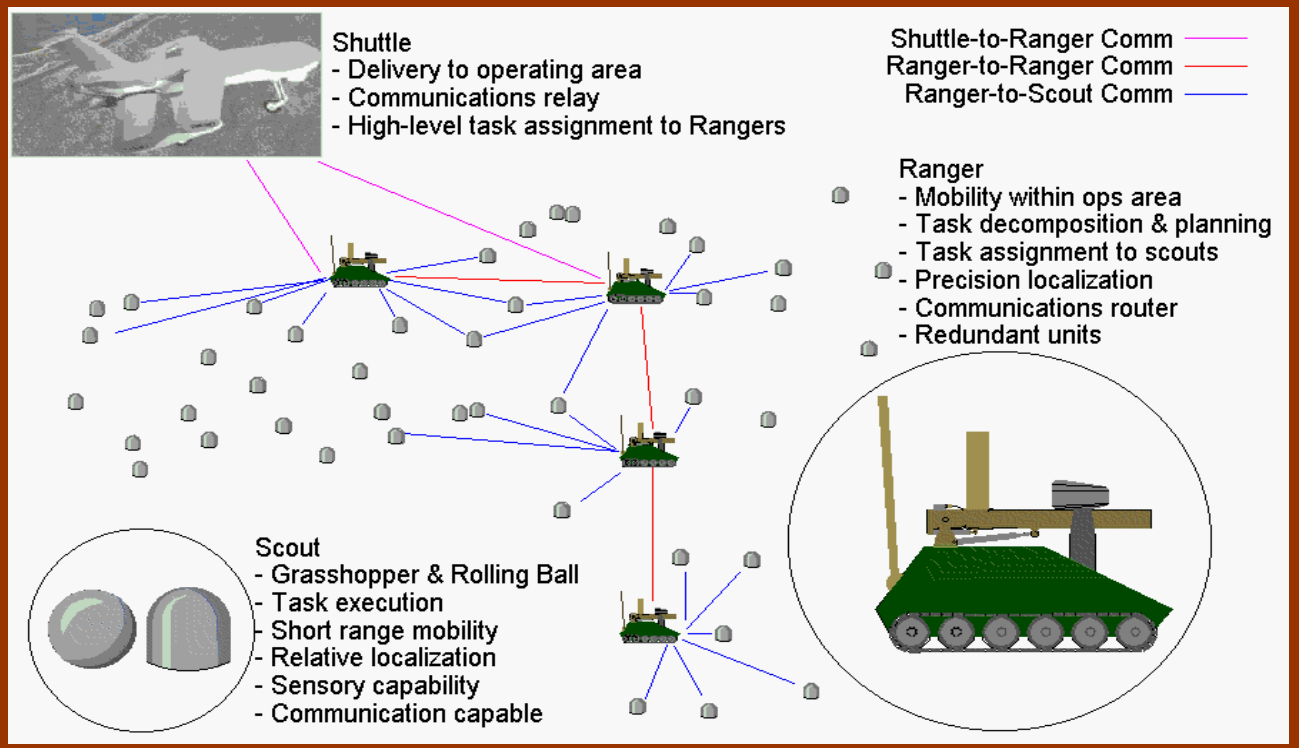
# Scouts and Rangers

- DARPA Distributed Robotics Program
- Hierarchical
- Heterogeneous

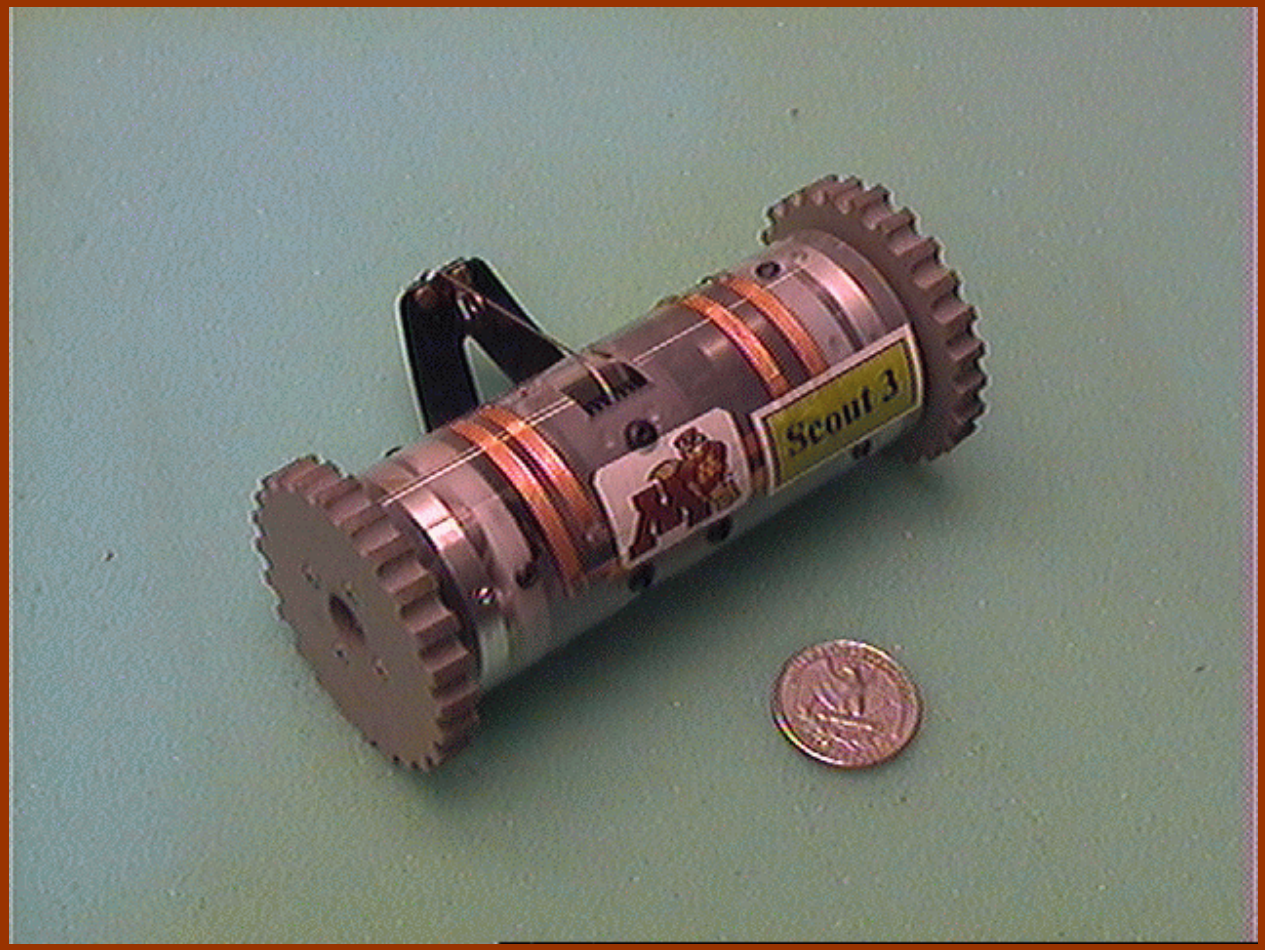


# Ranger Macrobot

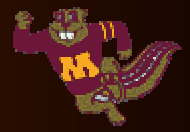
- **Covers Long Distances**
- **Remote Brain for Scout**
- **Localization Capability**
- **Carries and Launches 10 Scouts**

# Scout Microbot

- **Rolling/Hopping Locomotion**
- **Compass, Tiltmeter, Communication**
- **Camera / Microphone / Vibration / Gas Sniffer**
- **Reconnaissance Surveillance Search/Rescue**

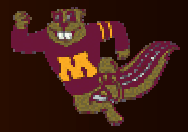


# Scout Design Constraints

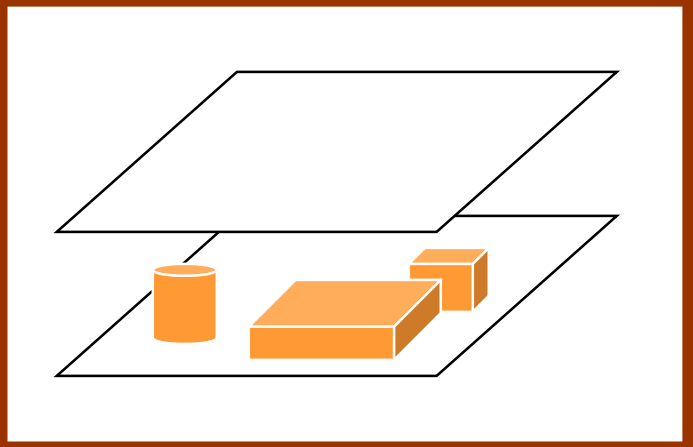


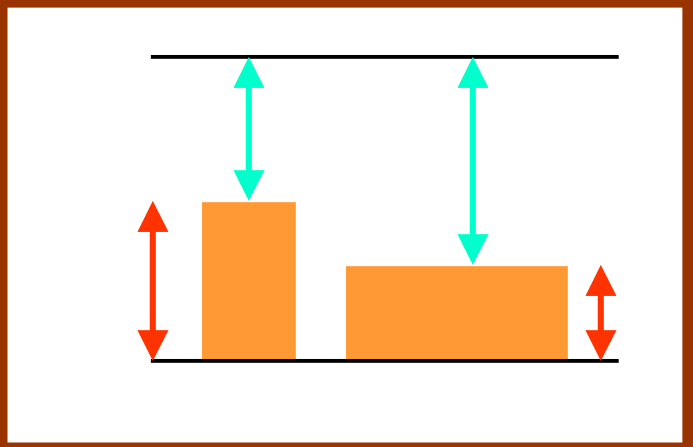
- **Form Factor: hard constraint on body diameter (< 50mm)**
- **Ruggedness: able to survive ballistic launching**
- **Adaptability: encounters a variety of unknown conditions**

# Scout Limitations



- No Ability to Manipulate (other than pushing)
- Can't Control Hop Height
- Can't Locomote when Headroom Only a Few Times Rubble Size

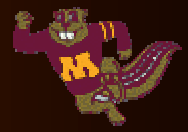




# Low Headroom Scenario

- Terrorism
- Warfare
- Earthquake
- Other Natural Disasters

# Alternate Design Goals

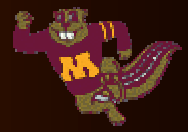


- Same Form Factor
- Same Ruggedness
- Same Power Constraints

- Greater Adaptability (low headroom)
- Dextrous Manipulation

- Dual-Use Limbs
  - Locomotion
  - Manipulation
- "Conserve Mechanism"
- Locomote by dragging the body

# Outline



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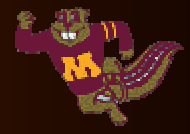
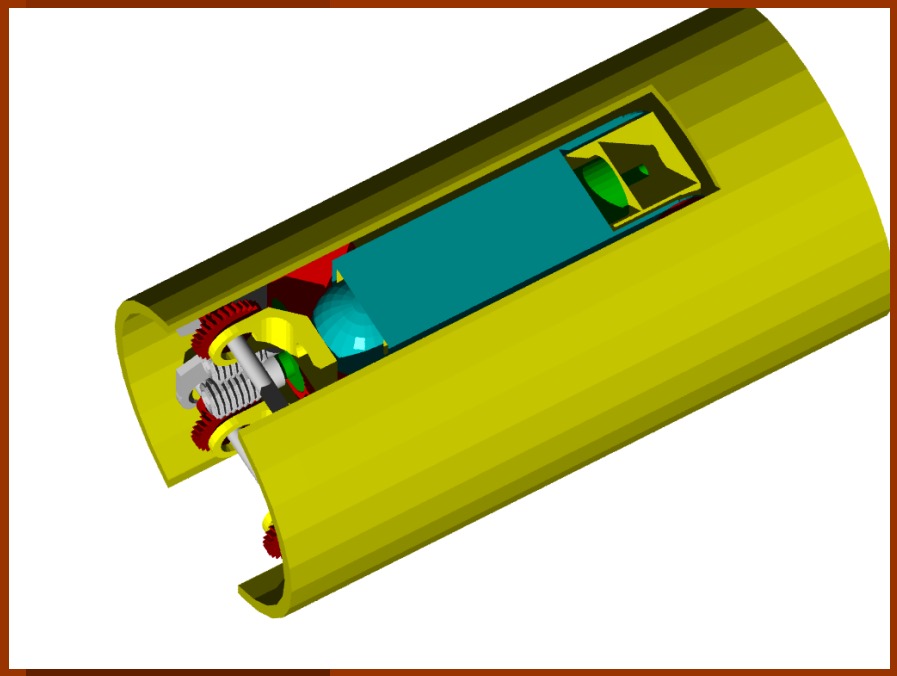
# *TerminatorBot* - Alternate Scout



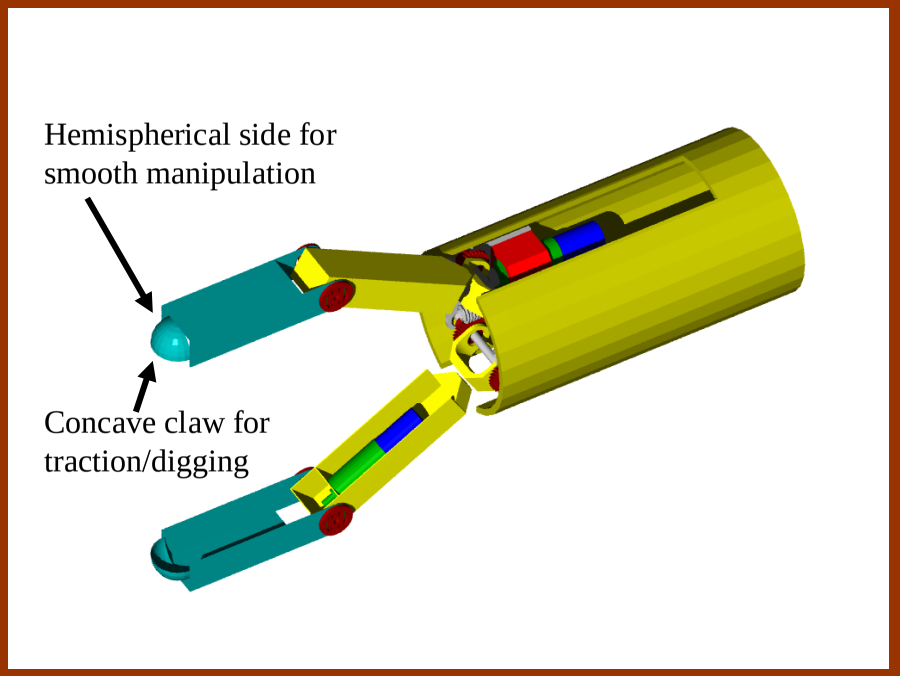
- **Two 3-DoF Arms that Stow Inside Body**
- **Dual-Use Arms for both Locomotion and Manipulation**
- **Four Locomotion Gait Classes:**
  - **"Swimming" Gaits (dry land)**
  - **Narrow Passage Gait (no wider than body)**
  - **"Bumpy Wheel" Rolling Gait**
  - **"Body-Roll" Dynamic Gait**

# TerminatorBot Form Factor

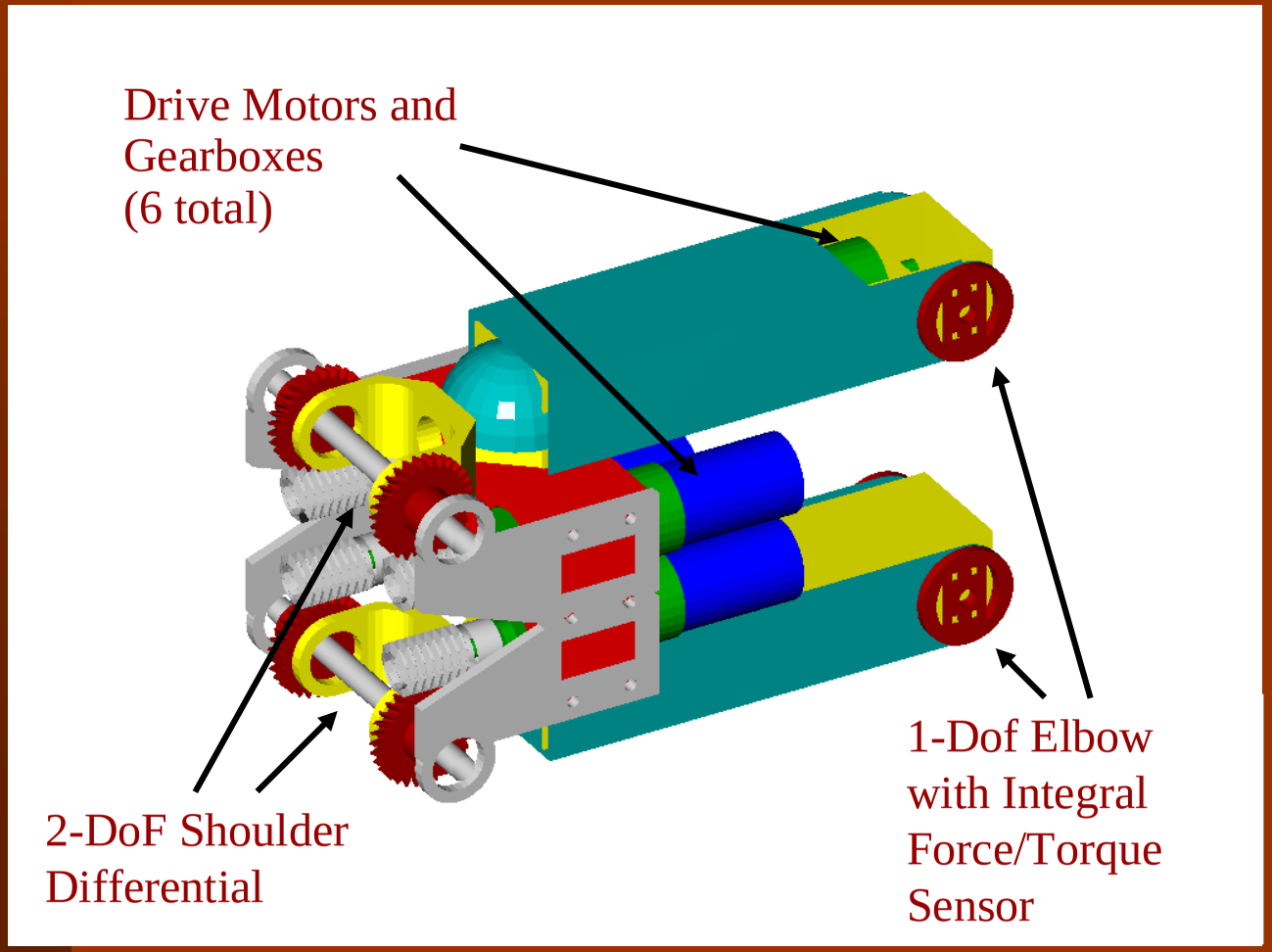
## Stowed Configuration



## Deployed Configuration

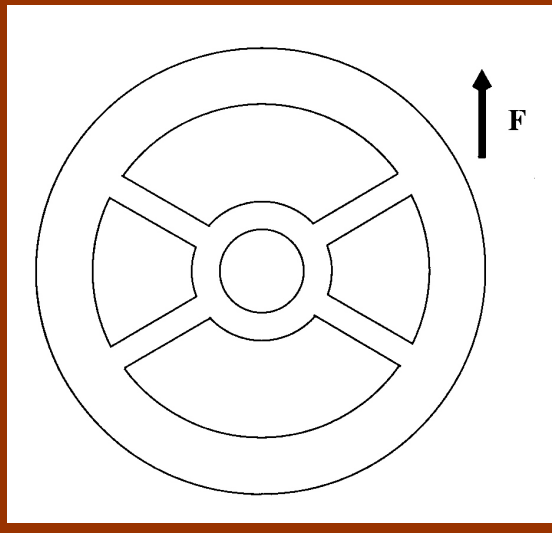


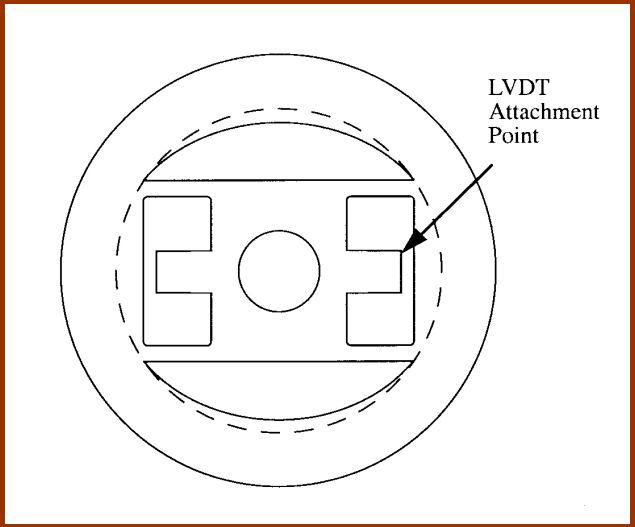
# TerminatorBot Design



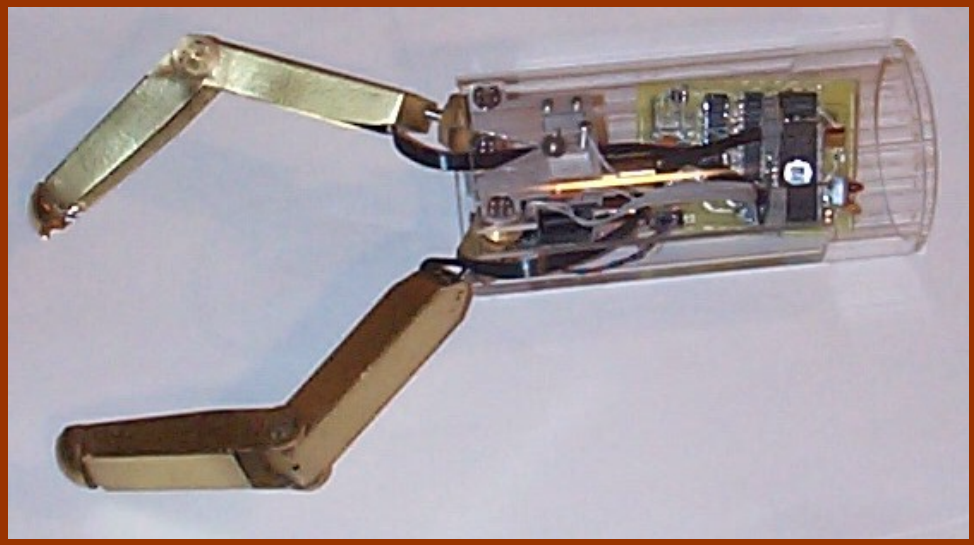
# Elbow Force/Torque Sensors

- Maltese Cross is isotropic but torque saturates
- Top Figure has higher sensitivity to forces of interest, but torque saturates
- Bottom figure “equalizes” torque
- Use LVDTs to avoid cross-coupling (Khatib, et al)



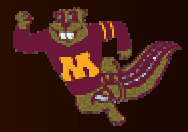



# TerminatorBot Prototype



- **1st Prototype is 75 mm in Diameter (approx. 2x scale)**

# Outline



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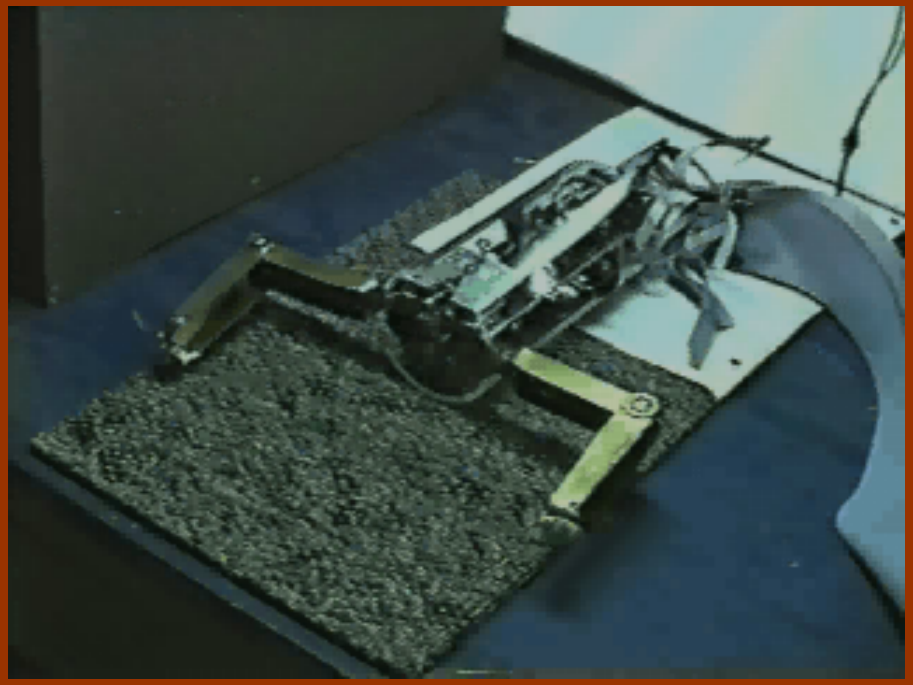
# Swimming Gait Video

- **“Expected” Gait**
- **Variable Body Height**
- **Adaptable to Terrain**

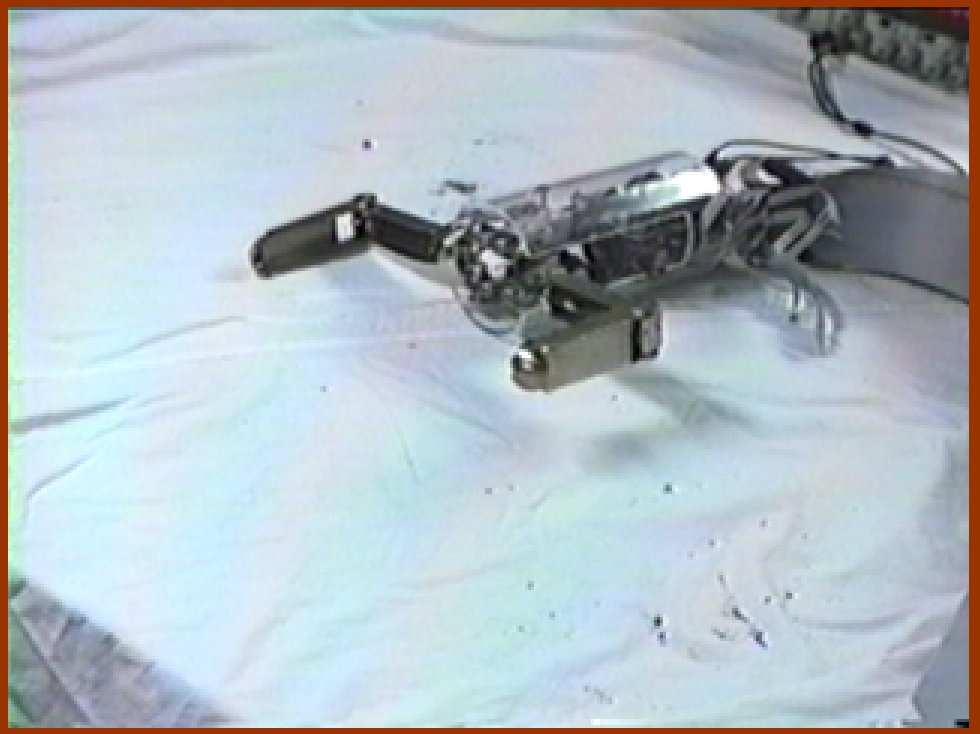


# Narrow-Passage Gait Video

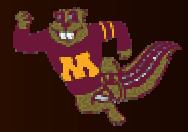
- **New Mechanisms Often Suggest Novel Gaits (Yim, Xu, Pai)**
- **Non-Controllable Body Height**
- **Good Traction**
- **Arms Stretched Out in Front of Body**

# Bumpy Wheel Gait Video

- **Non-Controllable Body Height**
- **4 Coupled Motors**
- **Forearms “Roll” Like the Spoke of a Wheel**

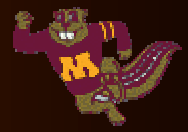


# Body-Roll Gait



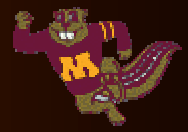
- Use Dynamics to Roll the Body
- Requires Smooth Surface
- Swing One Arm Across Body
- Use Other Arm as Reaction Force
- Tuck Swinging Arm to Roll
- Un-implemented at this time

# One-Armed Gaits



- **Fail-safe Operation**
  - **Emergency Homing Measures**
  - **Graceful Degradation of Mission Performance**
- **Body-Roll Gaits**

# Outline



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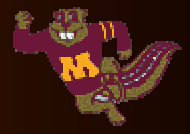
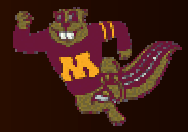
# Locomotion Primitives and Skills



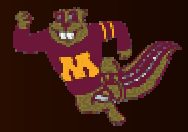
- **Patterned after prior work in manipulation (Morrow, Voyles)**
- **Gaits = Locomotion Skills**
  - **Gaits composed of collections of primitives**
  - **Gait cycles through primitive space**

# Simple Primitives



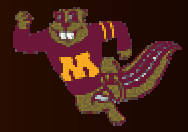
- **Open and Closed Loop**
  - **Joint-space trajectory segment**
  - **World-space trajectory segment**
  - **Torque command**
  - **Guarded move (sensor response)**
- **Evaluation Metrics**
- **Based on Port-Based Adaptable Agent Architecture (PB3A)**

# Learn to Evaluate Gaits



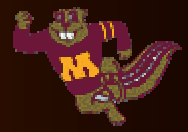
- **Metrics**
  - **Vertical Visual Servoing Error**
  - **Kinesthetic Sense of Torque**
  - **Visual Odometry**
- **Eigenspace-Based Learning Approach (PBD)**
- **Currently Applying Towards Conventional Mobile Robots**
- **Morph Gaits from Closed- to Open-Loop**

# Summary and Future Work



- **Robot Design**
- **Novel Gaits**
- **Topics Under Investigation**
  - **Gait Adaptation to Terrain**
    - **Learning Progress Metrics**
    - **Gait Morphing**
  - **Learning Manipulation Primitives**
    - **Primordial Adaptation (Eigenspace Method)**
    - **Programming by Demonstration**

# Sponsors



- **DARPA / MTO**
  - **Distributed Robotics Program**
  - **contract MDA972-98-C-0008**
- **Air Force Research Lab**
  - **Self-Adaptive Software Program**
  - **contract F30602-96-2-0240**