Colonies of ANTS supporting the advanced habitation and development of space MC34-55

End-to-End Architecture

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An introduction to ANTS

ANTS is a system architecture based on three key principles.
1. Multi-level autonomy
2. Specialization & division of labor
3. Coordinated behavior

The architecture is an analog of social insect colonies.
Individual elements are
highly autonomous,
highly capable, but
highly dependent on each other
to meet system goals.

Evolution towards ANTS-based systems
ANTS draws on established technological trends.
1. Advanced computing & communications
   - High performance computing
   - Reliable & autonomous systems
   - Reconfigurable systems
2. Agent-based systems
3. Distributed Systems
   - Multi-agent systems
   - Distributed in space and size (chips to constellations)

Development approach
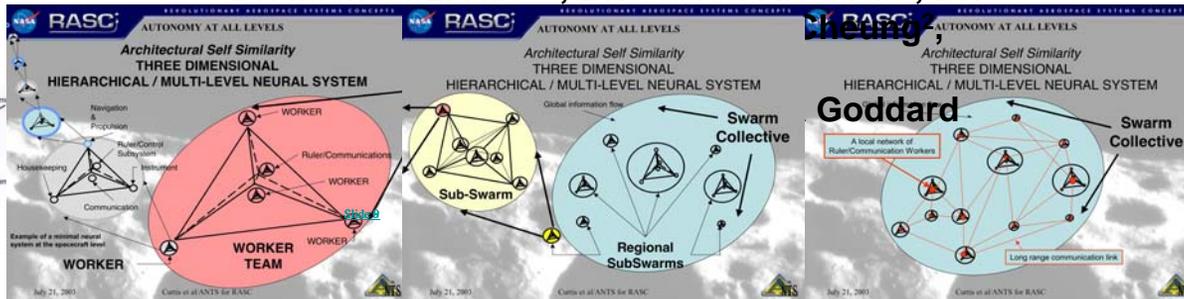Ongoing research is centered at NASA Goddard SFC.
1. Architecture development
   - ANTS & Distributed Space Systems
2. Mission/System conceptualization
   - Prospecting Asteroid Mission (RASC)
   - Advanced Solar Imaging Radio Array (proposed)
   - Saturn Autonomous Ring Array (RASC proposal)
3. Autonomy & Agent Technology Development
   - Spectral Analysis Agent (w. UMBC & WPI)
   - Space Technology 8 - Radio Astronomical Imaging (w. JPL)
4. Software modeling & simulation
   - ANTS-Sim (multi-agent / multi-spacecraft)
5. Engineering models
   - Addressable Reconfigurable Technology (proposed)

Summary Results
1. ANTS architecture for DSS study & design
   - Rethinking the role of the spacecraft bus
   - From mission focus to infrastructure
2. ANTS architecture has been applied to the problem of exploring the Main Belt Asteroids.
   - Mission concept in place, trade studies outlined
   - Next step: simulations
3. Research into ANTS has spun off a near-term mechanical design concept for an adaptive structure (ART).
   - Next step: engineering models & simulation
4. Initial concept for Saturn Ring exploration developed
5. ANTS-Sim models & simulation still in development
6. Onboard Radio Astronomical Imaging in study for ST8
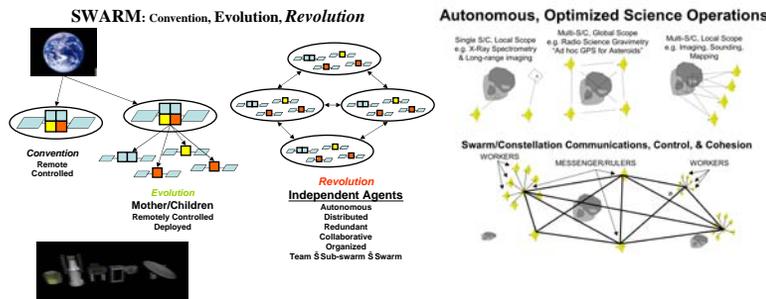   - Advanced onboard computing plays a key role

Web site: http://ants.gsfc.nasa.gov/

AUTONOMY AT ALL LEVELS
Architectural Self Similarity
THREE DIMENSIONAL
HIERARCHICAL / MULTI-LEVEL NEURAL SYSTEM

NANO-TECHNOLOGY ← **SWARM** → **DISTRIBUTED SPACE SYSTEM**

Division of Labor

SPECIALIZATION & TEAMWORK

SWARM: Convention, Evolution, Revolution

Convention
Remote Controlled

Evolution
Mother/Children
Remotely Controlled
Deployed

Revolution
Independent Agents
Autonomous
Distributed
Redundant
Collaborative
Organized
Team Š Sub-swarm Š Swarm

Autonomous, Optimized Science Operations

Single S/C, Local Scope
e.g. X-Ray Spectrometry
& Long-range imaging

Multi-S/C, Global Scope
e.g. Radio Science Gravimetry
"Ad hoc GPS for Asteroids"

Multi-S/C, Local Scope
e.g. Imaging, Sounding, Mapping

Swarm/Constellation Communications, Control, & Cohesion

WORKERS MESSENGERS/RULERS WORKERS

Near-term Application

Addressable Reconfigurable Technology (ART) for Large Space Structures

Products
Reconfigurable structural node
ART Truss Architecture
Working Engineering Model Reconfigurable Active Truss
Transition Plan for MEMS Implementation

Objectives
- Scalable reconfigurable ART structural mesh
- Mass and volume efficiency
  - < 1 kg/m² area with a pathway to g/m²
  - Packing factors that scale with fabrication tech
    - Macro 10x – Micro 10⁴x- Nano 10⁷x
  - Y1: Design of Macro-scale ART Nodes
  - Y3: Macro models of multi-Node ART structure

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Schedule and Funding
Milestones	Year 1	Year 2	Year 3
Milestone 1	Design & Simulation		
Milestone 2		ART Node Fabrication	
Milestone 3			ART Mesh Integration

Advanced Application

Autonomous Nano-Technology Swarm

PHOTO ANTICS

Prospecting Asteroids Mission

ANTS/PAM : Mission Concept 2020

Asteroid belt
2. Self propelled transit
1. Assembly & release
Asteroid(s)
3. Long-Range Operations
Lagrange Point Habitat
Earth
4. Swarm (Fly by) Operations
6. A messenger carries findings to Earth when needed.
5. Repeat steps 3 and 4.

SCALABLE SELF-RECONFIGURATION

ANTS: Evolution of Near-Earth Space
"It's a small solar system after all."

- 1930s Balloons
- 1950s LEO
- 1970s GEO
- 2010s Mars
- 2030s Asteroids

RASC — AUTONOMY AT ALL LEVELS

Autonomous Nano Technology Swarm
Autonomous Worker Neural Software System: *ANTS* Worker
Neural Map for a Neural Basis Function

July 21, 2003   Curtis et al ANTS for RASC

RASC — SWARM: Contrasting *centralized vs. distributed*

Autonomous agents with *organizational plasticity* maintain functions.

Long lived, very reliable, *rigid* roles

Beginning of Mission

End of Mission

Conventional:
Function degraded
Operations complex
Success hampered

ANTS:
Function maintained
Capacity reduced
Operations simplify
Success ensured

Continuous redistribution, flexibility & optimization

July 21, 2003   Curtis et al ANTS for RASC

The Robert C. Byrd Green Bank Telescope, 100 meter diameter, with an Active Surface of 2209 actuators for high frequency radio astronomy, improvements will include holographic imaging and laser ranging for improved surface figure. Detail shows truss work behind the reflecting surface (NRAO/AUI/NSF). Addressable Reconfigurable Technology (ART) will enable launch packaging and in-space deployment of such structures.

GSFC Laboratory For Extraterrestrial Physics-Planetary Magnetospheres Branch

Autonomous Nano Technology Swarm
The Final Unexplored Frontier: The Asteroid Belt

GSFC IR&D

- Survey 1000 asteroids a year.
- Mission functions distributed across a thousand specialized spacecraft.
- Present nano-spacecraft extended into pico-spacecraft regime (~ 1 kg).
- On-board computation, artificial intelligence, heuristic systems.
- Emergent behavior at single, group, and swarm system levels.
- Solar sail propulsion: 0.8 AU/YR.
- Long & Short range communication.

About ten spacecraft subtypes based on science sensors, in two general classes.

Ruler/Messenger   Worker

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