GNC application cases needing multi-core processors

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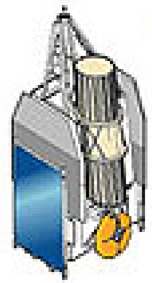
Day 3 (Thursday 27/10/2011)

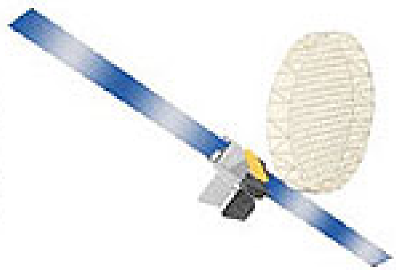
Multi-Core Processors for Space Applications

European Space Agency

Advanced control for current challenging missions

- Modern advanced space Guidance, Navigation, and Control (GNC) systems are now common ground for current space vehicle systems
- Nowadays common examples of space missions that need and utilize extensively advanced GNC systems:
  - Large satellites with flexible appendages,
  - flight dynamics and precise control of ascent vehicles,
  - control of a tight satellite formation,
  - precision landing on a rocky surface,
  - rendezvous with a space station





GNC definitions used here…

- GUIDANCE: establishment of the nominal path to follow (current, i.e. in real-time and future)
- NAVIGATION: establishment of the current state
- CONTROL: actions to match the current state (navigation) with the foreseen path (guidance)


ECSS-E-60A
14 September 2004

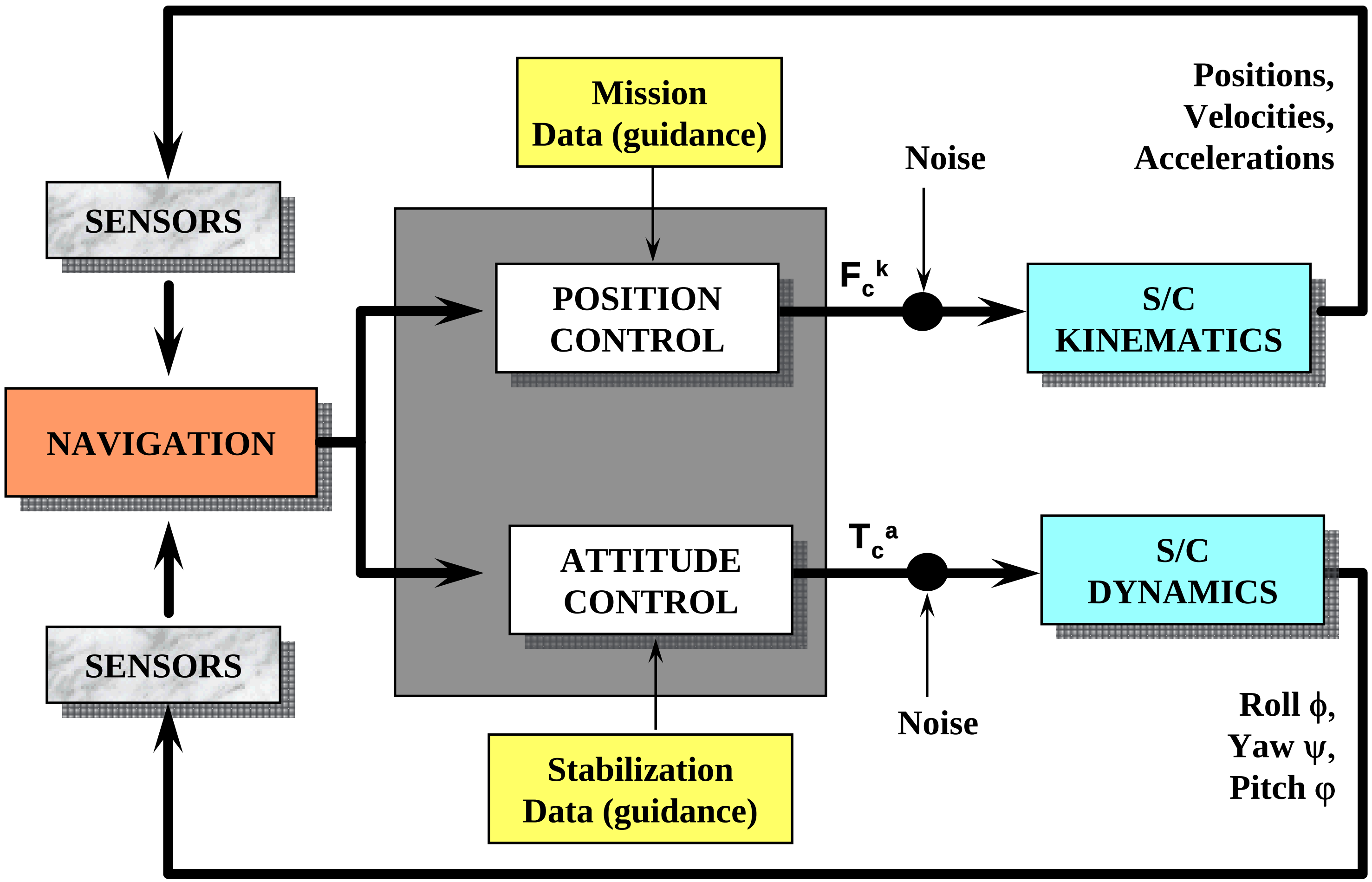
EUROPEAN COOPERATION
ECSS
FOR SPACE STANDARDIZATION

Space engineering

Control engineering

ECSS Secretariat
ESA-ESTEC
Requirements & Standards Division
Noordwijk, The Netherlands

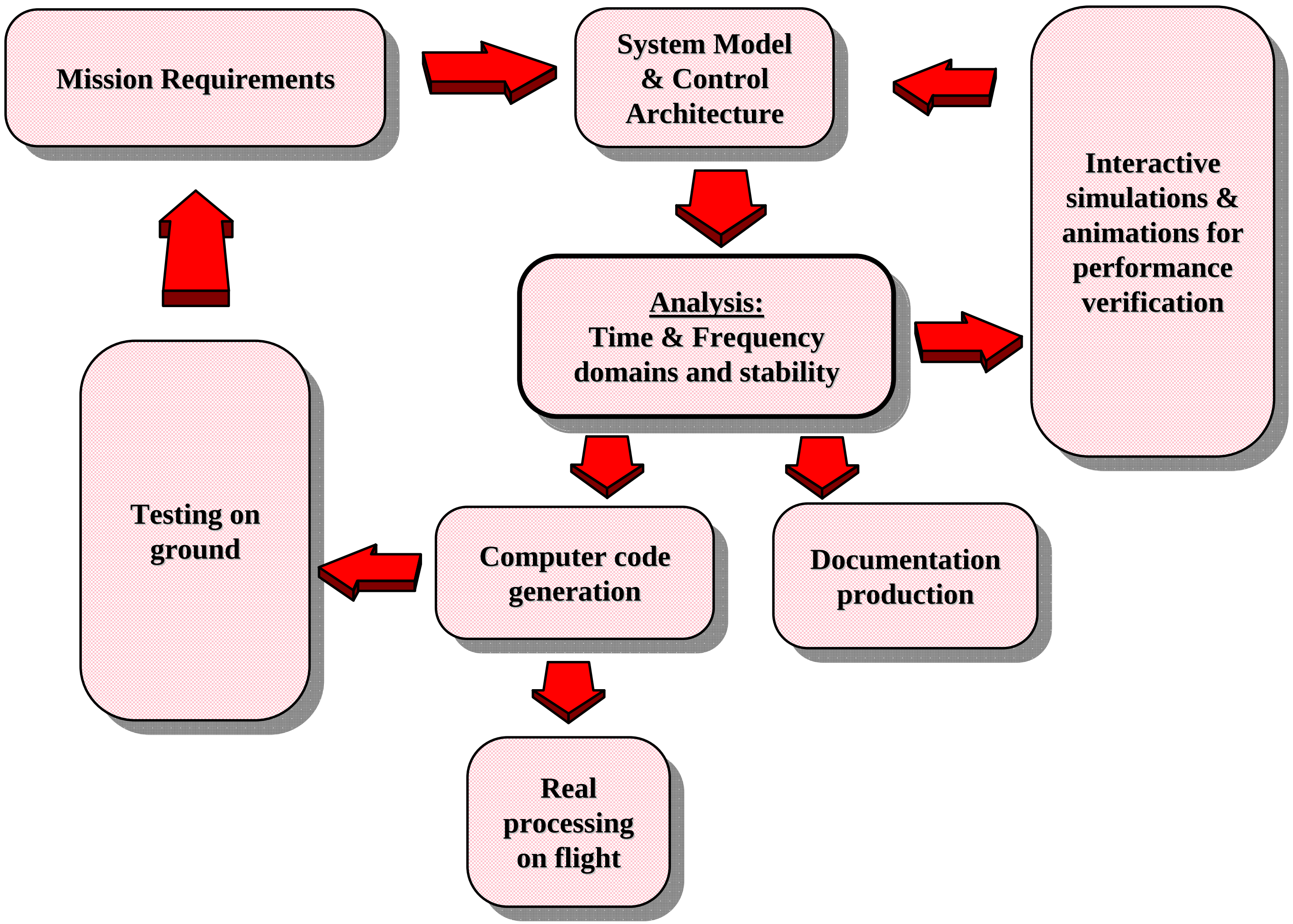
Guidance, Navigation, and Control subsystem



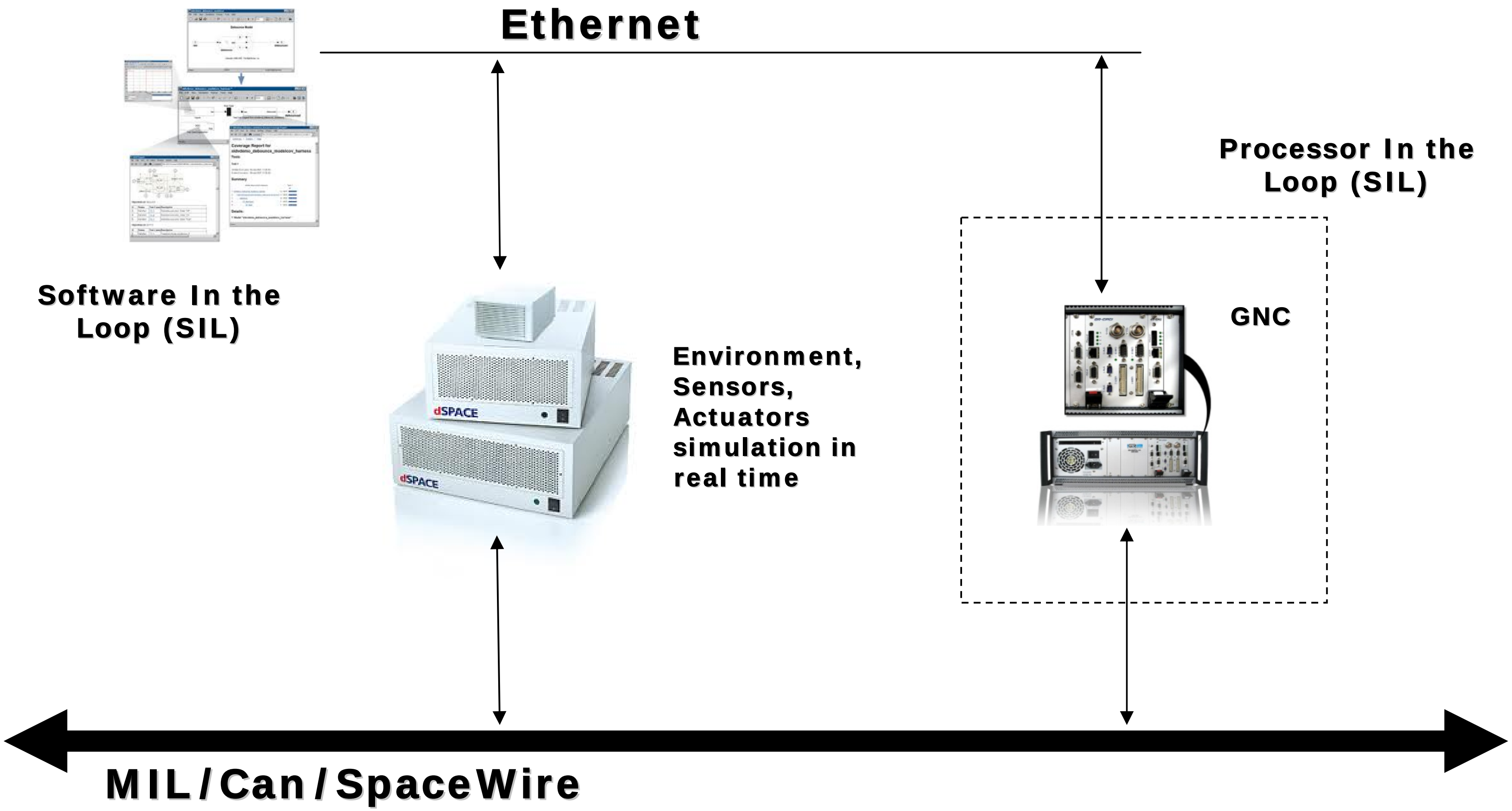
“Classic” GNC development cycle

- From MIL to SIL:
  - A simulator with “Models In the Loop” MIL is build to verify requirements and performance
  - The MIL is upgraded to SIL. The SIL has the capability to obtain source code from the MIL models
- From SIL to code:
  - Some of the SIL parts are converted into native code (C or Ada) either manually or automatically
- Using a PIL or HIL to test GNC out:
  - The code is checked into a representative avionics bed (either Processor In the Loop PIL or Hardware In the Loop HIL)
  - PIL, HIL allows to obtain foot prints...

"Classic" GNC development cycle



GNC testing “on-ground”



Outputs of the GNC testing on-ground

- Verification and validation of the GNC design versus requirements and specifications

Foot print	Failures
CPU load	Triggering of safe-mode
RAM use	Triggering of safe-mode
Number of processes	Excessive CPU load
Frequency of execution	Delay in the commanded forces and torques. Delay in the acquisition of data from sensors
Latency of GNC communication with devices	Limit-cycles that the control algorithm could not overcome

Can advanced GNC be "fit" into current computer architectures?

- GUIDANCE: are current on board processors are unable to fulfill required needs properly for complex guidance schemes?:
  - Real-time re-targeting function
    - Trying to change the trajectory based on an acquired image
    - Needs: 1 Hz / 8 Gb RAM / 1 process / 100 MIPs
  - On-board trajectory optimization function
    - Creation of a new trajectory after a failure or mission or vehicle reconfiguration
    - Needs: 10 Hz / 1 Gb RAM / 1 process / 120 MIPs

Can advanced GNC be “fit” into current computer architectures?

- NAVIGATION: are current on board processors are unable to fulfill required needs properly for complex navigation functions?:
  - Image processing
    - Point extraction and point tracking (200 points, 20 Hz, fast image processing)
    - Needs: 20 Hz / 8 Gb RAM / 1 process / 200 MIPs
  - Data fusion
    - Needs: 10 Hz / 8 Gb RAM / 1 process / 200 MIPs
  - State vector filtering
    - Needs: 1 Hz / 1 Gb RAM / 1 process / 10 MIPs
  - Classic sensor data processing
    - Star tracker with several heads

Can advanced GNC be “fit” into current computer architectures?

- CONTROL: are current on board processors are unable to fulfill required needs properly for complex control performances?:
    - Model-based predictive (formation flying)
        - Prediction of the plant state in the near future
        - Needs: 10 Hz / 1 Gb RAM / 1 process / 50 MIPs
    - H-infinity (rendezvous)
        - Robust control when many perturbations are affecting the vehicle under control
        - Needs: 1 Hz / 3 Gb RAM / 1 process / 50 MIPs
    - Dynamic inversion (entry)
        - Needs: 5 Hz / 1 Gb RAM / 1 process / 50 MIPs

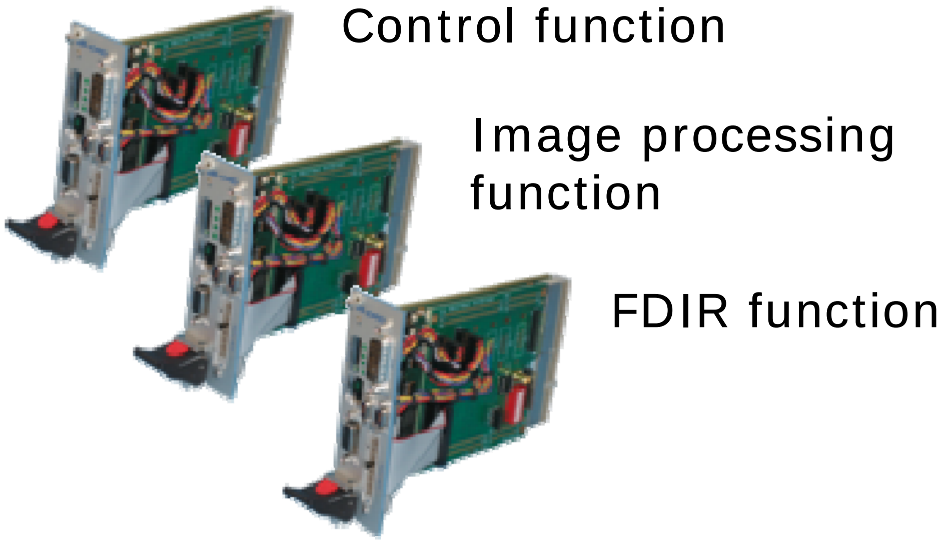
Can advanced GNC be “fit” into current computer architectures?

- FDIR and HMS: are current on board processors are unable to fulfill required needs properly for complex FDIR and HMS architectures?:
  - Fault detection and isolation (voting, isolating, ...)
    - Needs: 1 Hz / 0.5 Gb RAM / 1 process (entry)
  - Failure recovery (autonomous real-time reconfiguration)
    - Needs: 1 Hz / 0.5 Gb RAM / 1 process (RvD)
  - Mode transition management
    - Needs: 10 Hz / 1 Gb RAM / 1 process
  - Health monitoring system (failure prediction)
    - Needs: 10 Hz / 1 Gb RAM / 1 process

Current solution for advanced GNC

- A single core computer is duplicated, triplicated, quadruplicated, …
- Each computer is devoted to a particular function
- Some times, RAM is shared between computers

- **Are multi-core architectures able to cope with the CPU demand requested?**

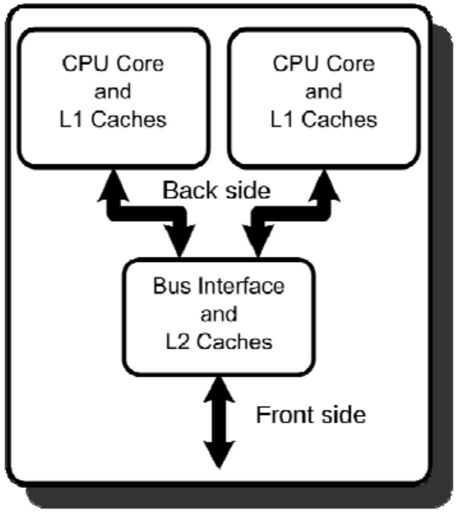


Multi-core computers

- “***...A multi-core processor is a single computing component with two or more independent actual processors (called "cores"), which are the units that read and execute program instructions...***”
- The improvement in performance depends very much on the software algorithms used and their implementation
- **ADVANTAGES**: operate at a much higher clock-rate, improved response-time while running CPU-intensive processes, much less printed circuit board (PCB) space, higher performance at lower energy

L.F.1

- **DISADVANTAGES**: adjustments both to the operating system (OS) support and to existing application software, need for sharing the same system bus and memory



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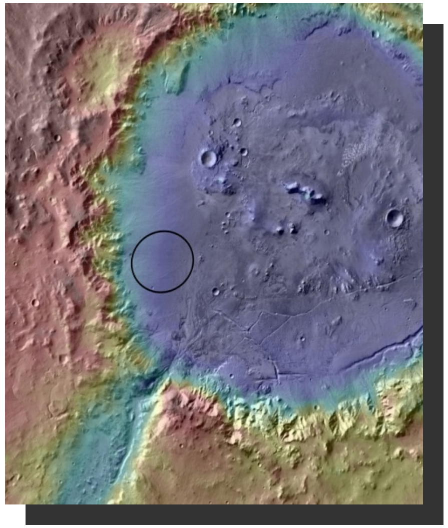
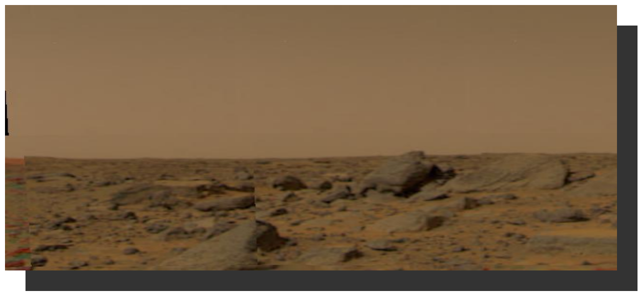
L.F.1 It is actually quite the opposite, multi-core architectures have, in general, a lower clock rate than single core ones.
Luca Fossati, 24/10/2011

Case 1: intelligent Entry, Descent, and Landing (iEDL)

- Computation of optimal trajectories and optimal control command in real□time
- Safe landing on a rocky surface (planet, moon, asteroid) requires the planning and execution of many actions is real time
- The acquisition of the sensors is continuous, leading to complex filtering navigation algorithms (e.g. data fusion)
- The control function provides the exertion of commands that are calculated optimally (e.g. model□based predictive control)
- The guidance function leads to a recalculation of the entire left trajectory all in real□time (e.g. dynamic optimal inversion).





Needs: 20 Hz / 16 Gb RAM / 5 process

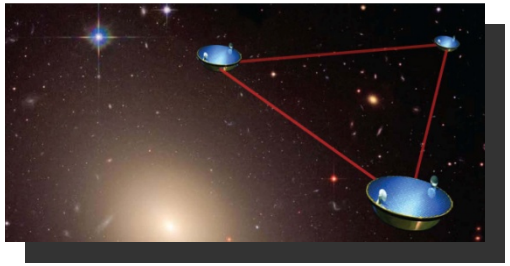
Case 2: large satellite with large flexible appendages

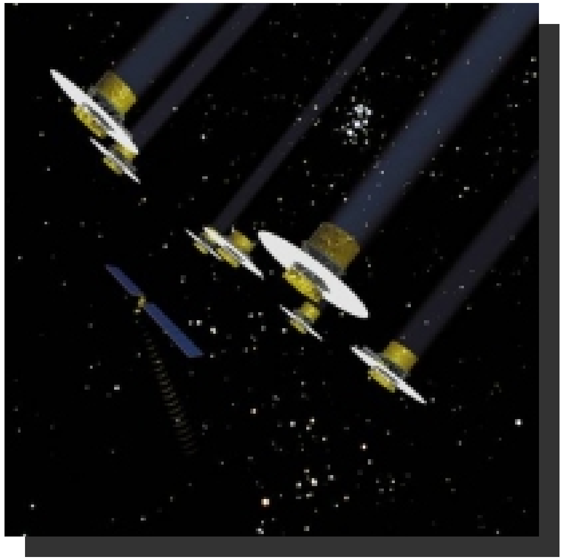
- Large antennae or large solar arrays have arrived to the markets of telecommunication satellites or observation of the Earth satellite missions
- The control of the compound platform plus appendages is very complex
- The matrix of inertia of such satellites creates problems in the control of the attitude slew maneuvers and the control of the attitude pointing stability
- New control paradigms have been developed as to cope with this problem but the proposed solutions by the GNC engineer do not fit on the current CPU architectures.

Needs: 10 Hz / 8 Gb RAM / 6 process

Case 3: tight formation flying

- The challenging problem in this case is to keep a tight formation between several spacecraft with millimeter accuracy
- Only advanced control techniques are able to establish the correct computation of actions on the formation to keep the geometry
- Target acquisition and re-targeting function for formation flying control





Needs: 10 Hz / 8 Gb RAM / 5 process

Examples: The DLR MUSE project, Multi-core architecture for tracking SEnsor in space

- To evaluate the capabilities of the multicore processor technology for future satellite missions the German Space Agency (DLR) initiated a research activity by funding the MUSE project
- The objective of MUSE is to design and implement a high performance processing system based on newest multicore processor technology
- To demonstrate the advantages of the multicore approach and in particular the performance of the prototype system, a complex tracking sensor application will be implemented
- The input generated by multiple high resolution camera systems will be processed in real time by different algorithmic solutions and different parallelization strategies to examine how multicore processors can be used optimally for typical computeintensive aerospace applications
- http://www.first.fraunhofer.de/en/department_quality_assurance/current_projects/muse/

Example: The NASA OPERA multicore initiative

- OPERA is the US Government’s near-term low cost multi-core processor solution:
  - NASA owns the OPERA multi-core intellectual property
  - The OPERA program’s Maestro chip provides processing leap-ahead capability for space applications
  - Breaks the paradigm of space electronics being a decade behind the commercial sector
  - Produces a radiation hardened state of the art general purpose processor
  - 100x more capable than current space qualified general purpose processors

Thanks for attending