SCOS-2000
ESA’s Spacecraft Control for the 21st Century

Presentation to GSAW 2003
4th – 6th March 2003
Nestor Peccia
Overview

- ESA Objectives, Working Plan and Challenges
- ESA Mission characteristics
- ESA Product Line
- History of ESA Control Systems
- SCOS-2000 in a Ground Segment Context
- SCOS-2000 Client missions and versions
- SCOS-2000 Architectural Concepts
- Lessons learned
- A vision for the future
**ESA Objectives**

- **Produce re-usable infrastructure (i.e. SW) system components**
  - State of the art technology to allow an effective evolution path
  - System designed to be used for any class of orbits
    - Low orbiting missions
    - Geostationary missions
    - Deep space missions
  - For any class of missions
    - Application missions
    - Scientific missions
    - Earth Observation missions
  - Advanced functionally geared towards a single operation concept / methodology
  - Re-use of same system whenever and wherever possible
    - MCS, EGSE, Station Control

- **Customise existing infrastructure components to meet mission specific needs**
  - Cost effective and fast deployment of a ground segment

THIS HAS BEEN ESA’s PRACTICE DURING THE LAST 25 YEARS
**ESA working methodology**

**Studies**
- Exploration of new Technologies and Functionalities
- Concept validation

**Infrastructure**
- Generic systems re-used for different missions and applications
- Long term mission profile

**Standardisation**
- Definition, production and reviewing of European and International standards (ECSS, CCSDS)

**Customisation**
- Mission Specific configuration, adaptations, extensions

**PROTOTYPES**

**STANDARDS**

**PRODUCTS**
The challenges

- In the area of software
- Software becomes an increasing element of the ground segment and is a major cost driver
- Harmonisation on software technologies
  - Platforms and OS
  - Languages
  - Standards (e.g. for interface)
- Harmonisation on software methodologies
  - Methodology (O-O)
  - Development and test tools
  - Project control and documentation (ECSS-E40)
Product Line

- ESA has introduced many years ago the notion of operational software.
- ESA retains the full ownership on this category of software.
- However the ESA software license regulation allows any ESA member state company to get the license free-of-charge for any ESA operational software.
- This license of course is non-exclusive, cannot be sold, and has to be used only for peaceful purposes.
- Nevertheless it allows those companies to use this software in any offer (even on the world-wide market).
- Business is not made with this software, but rather with the services that can be provided using this software.
- It is a way for ESA to help the European industry to be more competitive.
Product Line

- This is pretty similar to the Open Source concept (with the restriction that it applies only to Europe).
- ESA is the “gatekeeper” of the software, retains the Intellectual Property Rights (IPR), and encourages any European company to use this software.
- It is operationally proven and benefits of many years of experience in operating different classes of missions and of successful MCS engineering.
- ESA is committed to keep this software alive for many years.
- Thus any company using it, may benefit from its further releases, which will include new functionalities as a result of a continuing study program.
- It is certainly more advantageous for a company to follow this line, rather than deriving its own product (which is also legally possible).
- Companies may also make improvements to the software, in which case the preferred approach is that they make them available to ESA, as candidate for inclusion in the product – this is in line with the Open Source approach.

Our best Product : SCOS-2000 ; 54 Licenses in 3 years
ESA Missions Characteristics

- Geostationary / Geosynchronous
  - Continuous visibility from single ground station
  - Constant altitude (36,000 Km)
  - Station keeping manoeuvres
  - High bandwidth
  - Uses: Telecommunications, Meteorological (Meteosat)

- Low earth orbit (RT and Store / Forward –L1, L2-)
  - Elliptical orbit
  - Limited visibility at ground stations
  - Data stored on board, and dumped when station visible
  - High bandwidth and data rates
  - demanding mission planning requirements
  - Uses: Science missions, earth observation

- Deep space
  - Limited visibility
  - Propagation delay (TM/TC)
  - Lower bandwidth
  - Long life, long periods of inactivity
  - Uses: Science missions
History of ESA control systems

- **MSSS - 1984-1996**
  - Centralised processing, monolithic applications supporting many spacecrafts of different types
  - Frame telemetry / telecommand processing
  - FORTRAN / Assembler

- **SCOS-I - Since 1989**
  - Centralised processing, original architecture based on MSSS (but one S/C per system)
  - Packet telemetry
  - No generic telecommand chain
  - FORTRAN / VMS

  - Distributed processing, new architecture
  - Packet telemetry
  - Generic telecommand chain incorporated
  - C++ / UNIX
Characteristics of a good MCS: ESA’s view

- The characteristics of a good Mission Control System to be used as generic infrastructure are as follows:
  - must be generic,
    - designed to serve wide range of missions,
    - customisable: easily adapted or extended,
  - must be open i.e. must have well defined interfaces,
  - should be well documented and easy to install and configure,
  - being able to run on popular platforms, avoiding as far as possible tie-in to one particular platform vendor;
  - minimising dependence on commercial off the shelf (COTS) software,
  - should have long-term support commitment from the supplier of the product,
  - should have product expertise available on competitive market, i.e. potential users are not locked into one provider of support;
  - can be easily distributed to potential users or “clients” i.e. distribution is not blocked by issues of Intellectual Property Rights or licensing;

- All these issues have been considered when implementing SCOS-2000.
Complete system overview

Groundstations
- Kiruna (S)
- Redu (B)
- Perth (AUS)
- Villafranca (E)
- Kourou (GUY)
- DSN
- New Norcia (AUS)
- Cebreros (E)

ESANET WAN (X25) SLE

TM - Telemetry (housekeeping, dump, reports, science)
Tracking data

SCOS-2000 SERVER
MISSION PLANNING
FDS ORATOS

OPSNET

SCOS-2000 CLIENT

NCTRS

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Spacecraft control systems - LEOP system

MCR (15 w/s S2K Clients)

PSR (6 w/s S2K Clients)

SIM Room (2 w/s S2K Clients)

SSR (4 w/s S2K Clients)

PISA (2 w/s S2K Clients)

SIM Room (2 w/s S2K Clients)

DCR (6 w/s S2K Clients)

Mission dedicated H/W

Common Areas used for every mission

MCR : Main Control Room
PSR: Project Control Room
SSR : Software Support Room
PISA : PI Support Area
DCR : dedicated Control Room

NCTRS Prime

S2K Server Prime

NCTRS Backup

S2K Server Backup

S/C Simulator

Computer Room

Mission dedicated H/W

OPSNET (X25)

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An S2K based MCS in a GS Context

INTEGRAL
Ground Segment

INTEGRAL Overall Simulator (IOS)

PSS or Satellite

Operations Database (ODB)

Timeline Generator (MPS)

Flight Dynamics System (FDS)

Network Controller & TM Router System (NCTRS)

Monitoring & control System (IMCS)

Station Computer W/S

Remote Monitoring & Control

INTEGRAL Security Distribution System (ISDS)

Offline Evaluation System (PAS)

On-Board SW Maintenance System

Mission Archive

OPS Archive Long History File

TM & Aux. Data

Aux. Data

POS & ICP

Timeline Summary

Remote Access

Timeline Generator

Sequence

Schedule

TM / TC Definitions

EPOS

APF

TM / TC Characteristics

Operations

Database

(ODB)

Timeline

Generator

(MPS)

Flight

Dynamics

System

(FDS)

Network

Controller & TM Router System (NCTRS)

Satellite

DB Import

Operational DB Export

INTEGRAL
Ground Segment

S/W Images

S/W Images

TM & Aux. Auxiliary Data

CD ROMs

ISOC: Integral Science Operational Center

ISDC: Integral Science Data Center

ISOC

ISDC

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S2K Client missions

- ESA
  - Existing or completed:
    - SOHO – NASA Goddard, USA.
    - TEAMSAT - Experimental satellite
    - MTP – EUMETSAT
    - HUYGENS - Interfaces via NASA system at JPL, California.
    - PROBA - experimental satellite,
    - MSG - Meteosat Second Generation LEOP system.
    - INTEGRAL - International Gamma Ray Laboratory.
  - Development ongoing:
    - ROSETTA MCS - 10 year mission, launch 2004
    - Mars Express MCS - Mars exploration, launch 2003
    - SMART-1 MCS - experimental propulsion, launch 2003
    - Venus Express MCS
    - Cryosat MCS– First ESA mission on evolution platform
    - GOCE MCS
    - ADM MCS
    - Herschel / Planck MCS
    - ESA Vega Launcher EGSE (in evaluation)
    - Herschel / Planck Central Checkout System (EGSE) (Red Hat 7.2)
    - Galileo MCS (34 satellites) (in evaluation)
S2K Client missions

- External Users
  - Canada
    - Radarsat 2
    - Telecommunication Satellites (under evaluation)
  - German Space Agency DLR-GSOC
    - GRACE
    - BIRD
  - Eutelsat
    - New MCS system – NEO
  - Italian Space Agency – ASI
    - Cosmos Skynet
  - Italian Aeronautical research Centre
    - USV (unmanned Space Vehicle)
  - 20 European Scientific Institutes
    - Herschel / Planck Instrument EGSE (SUSE 7.3)
  - Japan
    - Telecommunication Satellites (under evaluation)
SCOS-2000 Versions

- **Classic**
  - Sun Hardware
  - Solaris 2.6
  - Costly COTS (Object Store, Orbix)
  - Culminates in version 2.4.1

- **Evolution (Release 2.1.e, 2.3.e)**
  - PC Hardware (HP, Dell..)
  - LINUX (SUSE 7.3) or Solaris 2.6
  - Open Source COTS (POST, OmniOrb)

- **Release 3.0**  January 2003
  - Classic + Evolution lines merged
  - Solaris 8
  - Archive Upgrades

- **Release 3.1**  September 2003
  - Linuxs OS migration to version SUSE 8.1 Professional
  - MMI migration to ILOG views vers. 5.0
  - Integration of upgrades done by different missions

- **Release 4.0**  June 2004
  - Multi-Mission (constellation, formation flying) (LEO, Geo, Deep Space)
  - Full EGSE compliant
**SCOS-2000 Architecture concepts**

- SCOS-2000 is a mission control system kernel
  - with commonality for spacecraft check-out systems and S/C software validation facilities
- SCOS-2000 is a set of object oriented components
  - allows re-use by system developers
- SCOS-2000 is a set of generic executables
  - may be used ‘as-is’ if functionality matches needs of users
  - provides basis and examples for client mission developers
  - allows generic functionality to be validated
- SCOS-2000 provides mechanisms for handling the functionality of spacecraft control and checkout control systems
- SCOS-2000 can be extended to cover functionality required by specific missions
- SCOS-2000 is a distributed and scalable system
- SCOS-2000 must be a configurable and open system
SCOS-2000 Enabling Technology

- **Object Oriented Analysis & Design**
  - Rational Rose (UML)
  - Unix, C++, STL
  - COTS:
    - ILOG views - GUI library
    - Ctree+ (packet archive)
    - ObjectStore [SCOS-2000 Classic]
    - Iona ORBIX (CORBA 2.1) [SCOS-2000 Classic]
    - OmniORB (fully CORBA 2.3 compliant) [SCOS-2000 Evolution]
    - POST++ [SCOS-2000 Evolution]

- **Space Standards**
  - CCSDS standards for Packet Telemetry and Telecommands.
  - ECSS Packet Utilisation Standards, a standard which defines the different packet types and sub-types in a systematic way, grouping them into a number of “services” that are offered between space and the ground.

- **Public Domain**
  - Flex, Bison (for OL parsing)
  - Tcl/Tk (old launcher - now not used)
  - a2ps (for postscript output printouts)
  - zlib (for packet compression)

- **Documentation**
  - MS-Word
  - GEORGE (HTML)

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Space Standards

- CCSDS standards for Packet Telemetry and Telecommands.
- ECSS Packet Utilisation Standards, a standard which defines the different packet types and sub-types in a systematic way, grouping them into a number of “services” that are offered between space and the ground.

SLE

- It is also possible to offer a suite of Ground Station Interface Software that is conformant to the Space Link Extension (SLE) standard, an CCSDS standard to allow more ready interoperability of ground stations between different operators.
SCOS-2000 Client / Server

CLIENTS:

SERVERS:

Client MMI Applications
- Desktop (alarm display)
- Monitoring Display Container (TM)
- OOL Display (TM)
- Event Logger (EV)
- Manual/Auto Stacks (TC)
- TC History (TC)
- Caches (TM/TC/EV)
- Configuration client (TM/TC Spacon)

Server Processes
- Packetiser (TM)
- Behaviour (Limits) checker (TM)
- Synthetic parameter packet generator (TM)
- Multiplexer, Releaser, Verifier, OBQM (TC)
- Archive (TM/TC/EV)
- Events & Actions Servers (EV)
- Configuration (MISCdynamic) server
## SCOS-2000 Software Layers

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<th>Layer</th>
<th>Sub-Layer</th>
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<tr>
<td>MMI</td>
<td>Telemetry Displays, Commanding, Procedure Execution, OnBoard Software Maintenance (OBSM), Roles &amp; Privileges, Event &amp; Action handling, Ground Station &amp; External Interfaces, MIB Applications (Database Access)</td>
</tr>
<tr>
<td>Telemetry Model</td>
<td>Operations Language, Command Model, User Model, Events &amp; Actions</td>
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<tr>
<td>Command Model</td>
<td>Archiving, Persistent Storage (DB)</td>
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<tr>
<td>User Model</td>
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</table>

- Telemetry Displays
- Commanding
- Procedure Execution
- OnBoard Software Maintenance (OBSM)
- Roles & Privileges
- Event & Action handling
- Ground Station & External Interfaces
- MIB Applications (Database Access)

- Operations Language
- Command Model
- User Model
- Events & Actions
SCOS-2000 System Overview

User inputs

TM frames
Report packets
Admin messages

TC requests
Configuration requests

SCOS-2000

NCTRS

S/C DATABASE MANAGER

PROCEDURES PRODUCTION TOOL

ON-BOARD S/W SDE

ASCII database

TC sequences

Memory images
Symbol tables

Dump memory images

TM packets

Task Parameter Files

TC saved stacks

Packets Requests Files (e.g. TDRS)

TM (params, packets)
Events
TC status

TC requests

TM (params, packets)
Events
TC status

ORATOS (flight dynamics)

MISSION PLANNING SYSTEM

EXTERNAL CLIENT SYSTEMS

MISSION SPECIFIC APPLICATIONS

TC saved stacks

Requests Files (e.g. TDRS)

TM packets

TC status

Events

Packets
System interfaces

- **Users**
  - Client system developers
  - End users
- **NCTRS - Network Command, Telemetry & Ranging System**
  - TMP4, TCE, MKII, MPTS MKIII, STC II
- **Database**
  - S/C database
  - Database editing tool
- **FOP PRODUCTION TOOL**
  - Command sequences (imported into MIB)
- **OBSM SDE**
  - OBSM image files (received, exported)
- **Flight dynamics (ORATOS)**
  - TM packets (real-time, retrieved)
  - Task parameter file (TPF)

- **Mission planning system**
  - Command schedules
- **Mission-specific MCS applications**
  - APIs
  - Low-level services
- **External systems (e.g. procedure execution systems)**
  - Packet
  - Parameter
  - Command
  - Event
Top level components

Monitoring

- TM transfer frames
- Report packets
- Admin messages

Data Archive & Distribution

- Event packets
- Files
- Retrieved image packets
- Dump TM
- Image import files

Commanding

- TC packets
- Image packets
- TC stacks
- Memory model definitions

Desktop & General applications

- Event packets
- Files

SCOS-2000 Importer

- ASCII database
- Dump memory images

OBSM

- Memory model definitions

MIB

- Static TM definitions
- TM parameters
- CLCW
- External generated TC definitions
- Admin messages
- TC encoded packets
- Static TM/TC definitions

TC encoded packets

- TM/TC/Event packets
- TC packets
- Image packets

SCOS-2000 Importer

- TM/Event packets Retrieval reqs.

External generated TC definitions

- TM parameters
- Retrieval reqs.

TM/Event packets

- TM/Event packets
- SSC parameter
- CLCW

SCCS parameter

- TM/Event packets
- SSC parameter
- CLCW
Commanding functions

- **Manual Stack**
  - **Load Commands**
    - Command encoding
    - Commands with parameters
    - Parameter de-calibration
    - Execution time-tagged
  - **Release Dependencies**
    - Grouping
    - Blocking
    - Delta release times
    - Interlocking
  - **Master Manual Mode**
  - **Wait Mode**
  - **Static/Dynamic PTV**
  - **Load Sequences**
    - Formal sequence parameters
    - Absolute start/execution time
  - **Load/Save**
    - Commands
    - Sequences
    - Stack files
    - TPFs

- **Autostack**
  - Restricted Manual Stack functions
  - No editing
  - Execution/Release based
  - **Multiplexer (allowing multiple sources to command in parallel)**
  - **Command releaser (interface to external command destination - NCTRS)**
  - **On-Board Queue Model (time-tagged commands)**
  - **Command verifier (performs multi-stage command verification and status consistency check disabling on affected TM parameters)**
  - **On-Board Queue Display (OBQD)**
  - **Command History Display**
  - **Command Query Display**
Monitoring functions

- **TM Packetiser**
  - Packet reconstruction (from frames)
  - CLCW Extraction
  - Quality checks
  - Continuity/sequence checks

- **Parameter extraction (super-commutation)**

- **Synthetic parameters**
  - OL-synthetic
  - Compiled OL
  - Hard-coded (C++)
  - Re-calculated for retrieved data

- **Parameter processing (calibration)**

- **Parameter validity**

- **Behaviour checking**
  - Limits
  - Expected Status
  - Status Consistency

- **Retrievals**
  - Retrieval start from given time
  - Datastream selection
  - Datastream merging (data from up to 4 streams merged on single displays)

- **Configuration**
  - Retrieval rate
  - Processing control (local, global)
  - Distribution via packet

- **Online changes**
  - Limit values
  - Calibration points
  - OL expressions (interpreted)
  - Alphanumeric displays
  - Graphics definitions
  - MIMICS editors
Monitoring functions

- **Displays**
  - Alphanumeric display (AND) - 32 or 64 parameters
  - Graphics (GRD)
    - 1-8 parameter vs. time
    - 1-8 strip chart emulation
    - 1-8 parameter vs. parameter
  - MIMICs
  - Scrolling (SCD)
  - Telemetry Query Display (TQD)
  - Out of limits displays
  - Events

- **Packet Displays**
  - Variable Packet Display
  - Telemetry Packet History Display
  - On-Board Event History Display

- **TM processing control (TM SPACON)**
  - Filing enable/disable
  - Reset status consistency check state
  - Extendable by missions

- **Synthetic parameter packet generator**
  - Allows permanent filing of database defined synthetic parameters
Distribution and filing

- Centralised filing of all received packets
  - Non-circular filing (continuous enlargement) using C-Tree+ COTS
  - Files split for long-term archiving
  - Fixed or variable length records
- Filing according to
  - Type (TM, TC, Event)
  - SCOS-2000 packet ID (SPID)
  - Datastream (logical grouping of data, e.g. R-T, playback)
  - Time
- Retrievals independent from real-time packet handling
- Distribution of packets to distributed client caches
  - TCP/IP
- Global filing enable/disable (from admin tool called PDSadmin)
- Hot switch to backup server
- HF administration tool (also PDAadmin primarily to be used by S/W support)
  - delete records, display configuration, dump/export/print packets, re-send packets, splits archive
Lessons learned

- Production of S/W re-usable infrastructure for all ESA missions controlled from our OCC at Darmstadt, Germany, has been a great success in the last 25 years.
- Open Source type approach with a licensing free-of-charge policy within Europe is proving to be excellent for our Industry in terms of competitiveness.
- European Industry is requesting ESA to enhance this approach to other Ground Segment Data System Infrastructure.

- This has lead us to our new framework.

- **EGOS (ESA Ground Operations Software system)**
A vision for the future

- EGOS is a family of products following the same SCOS-2000 approach
  - GSTV: Ground Systems Test and Validation
  - MCCM: Multi-mission Configuration Control Manager
  - GSMC: Ground Systems Monitoring and Control
  - NCTRS / SLE: Network Command and Telemetry Routing System
  - SIMSAT: Simulator Infrastructure
  - GFTS: Generic File Transfer System
  - GDDS: Generic Data Disposition System
  - OPS: Operations Preparation System
  - ADAS: Advanced Data Analysis System
  - APES: Automated Procedure Execution System
  - EVA: ESA Versatile Archive
  - EGSE: Electrical Ground Support Equipment
  - MPS: Mission Planning System
  - TMTCS: TM and TC BaseBand System
  - FDS: Flight Dynamics System