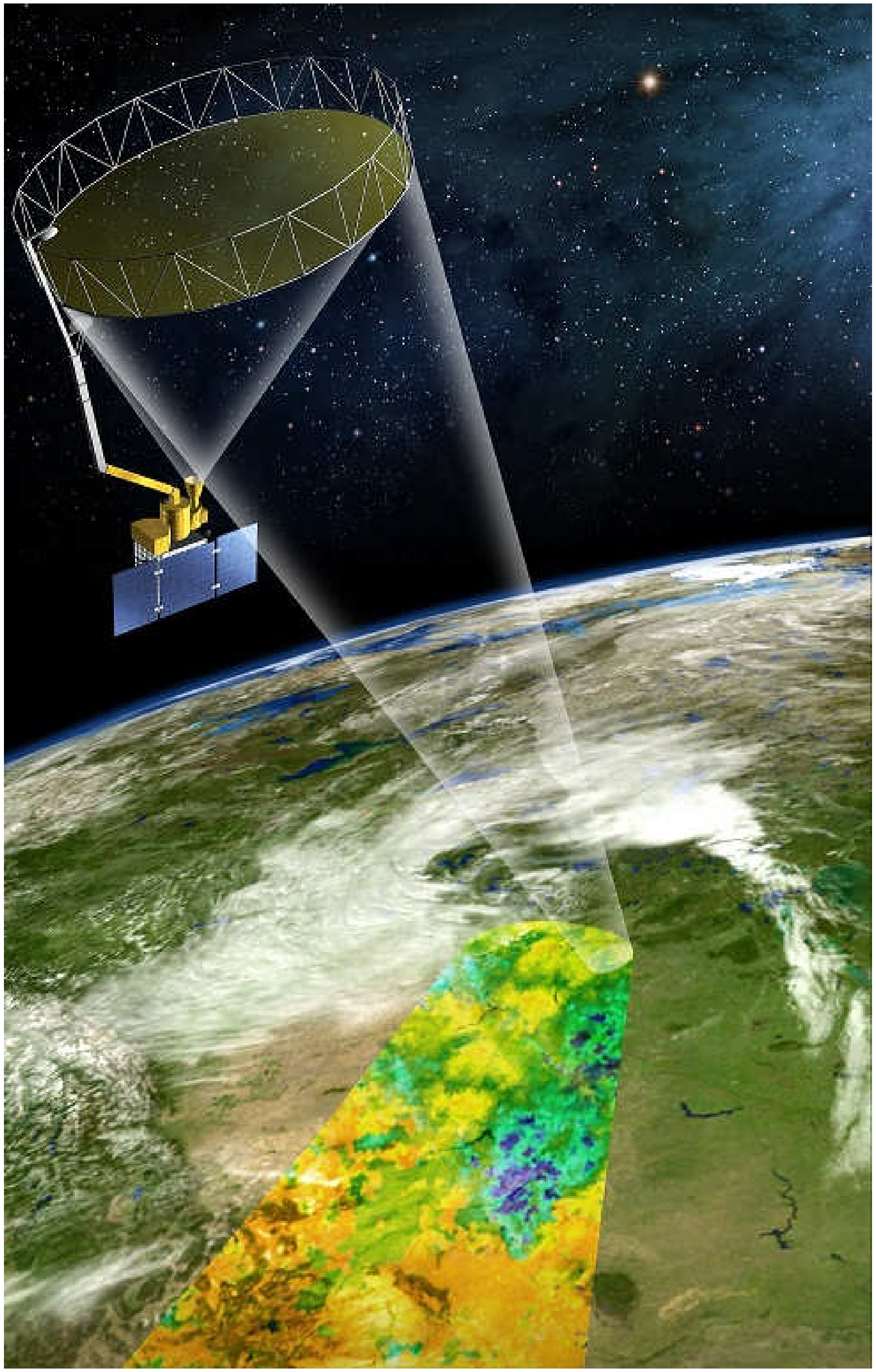

Autocoding and Dictionaries on SMAP and MSL

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http://smap.jpl.nasa.gov/
http://mars.jpl.nasa.gov/msl/

Agenda

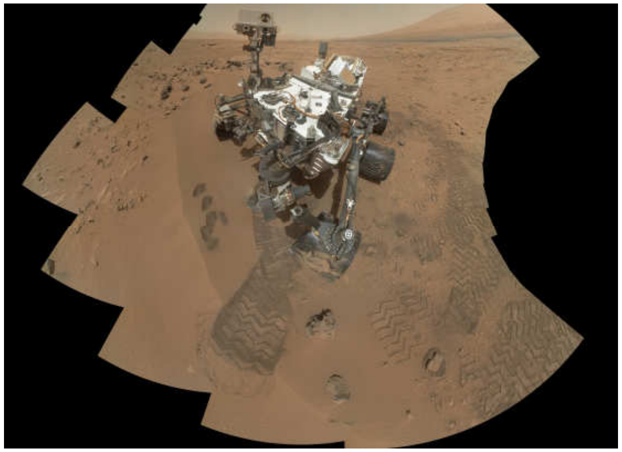
- Summary
- Mission Overview / Dictionary Overview
- MSL Dictionary/Autocoding Process
  - Commands/IPC Messages
  - Engineering Health and Accountability (EHA)
  - Event Record (EVR)
  - Data Products (DP)
  - Parameters
- MSL Lessons Learned
- SMAP Dictionary/Autocoding Process
  - Commands/EHA
  - EVR
  - Data Products
  - Parameters
- SMAP Lessons Learned
- MSL/SMAP compare contrast

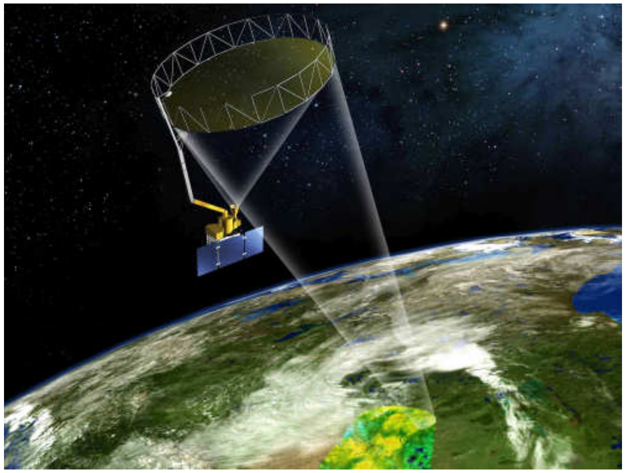
Executive Summary

- Both SMAP and MSL
  - Used XML dictionaries for commands, telemetry and data products.
- The MSL and SMAP missions made extensive use of autocoding
  - Autocoding
    - Generating flight C code from XML
- MSL
  - Developers wrote the autocoder input XML by hand
- SMAP
  - Leveraged lessons learned from the MSL
  - Streamlined requirement sources
    - Used XML dictionaries for more types of specification
  - Used a web/database tool called Dictionary Management System (DMS) to:
    - Specify dictionary elements
    - Generate XML
      - Dictionaries
      - Autocoder's XML inputs

Mission Scope/Overview

- MSL Overview
  - Latest Mars rover mission
  - Three mission phases
    - Cruise
    - Entry, Descent, and Landing
    - Surface
  - Highly redundant hardware
  - 10 instruments
  - Mobility system with autonomy
  - Drill
  - Robotic arm
  - Cameras
- SMAP Overview
  - Earth orbiter
  - Mostly single string with a few redundant devices
  - 2 instruments
  - Rotating spun section
  - Complex mechanical deployment
- Same flight software architecture for both missions
  - Written in C
  - Operating system: VxWorks
  - Architecture: Message passing via Inter-Process Communication (IPC)





Dictionary Overview

- Dictionary:
  - A machine-readable file that describes commands and telemetry formats
  - Allows ground tools to
    - Encode commands
    - Decode telemetry and data products
  - Is consistent between flight software and ground software
  - Contains human-readable command and telemetry descriptions

Code / Dictionary Comparisons

MSL	Raw KLOC	Physical KLOC	Logical KLOC
Handwritten C	1,323	788	470
Handwritten XML	409	368	277
Autogenerated C	4,049	2,563	1,101
Autogenerated XML	1,846	1,649	1,258
Total (XML and C)	7,629	5,369	3,107

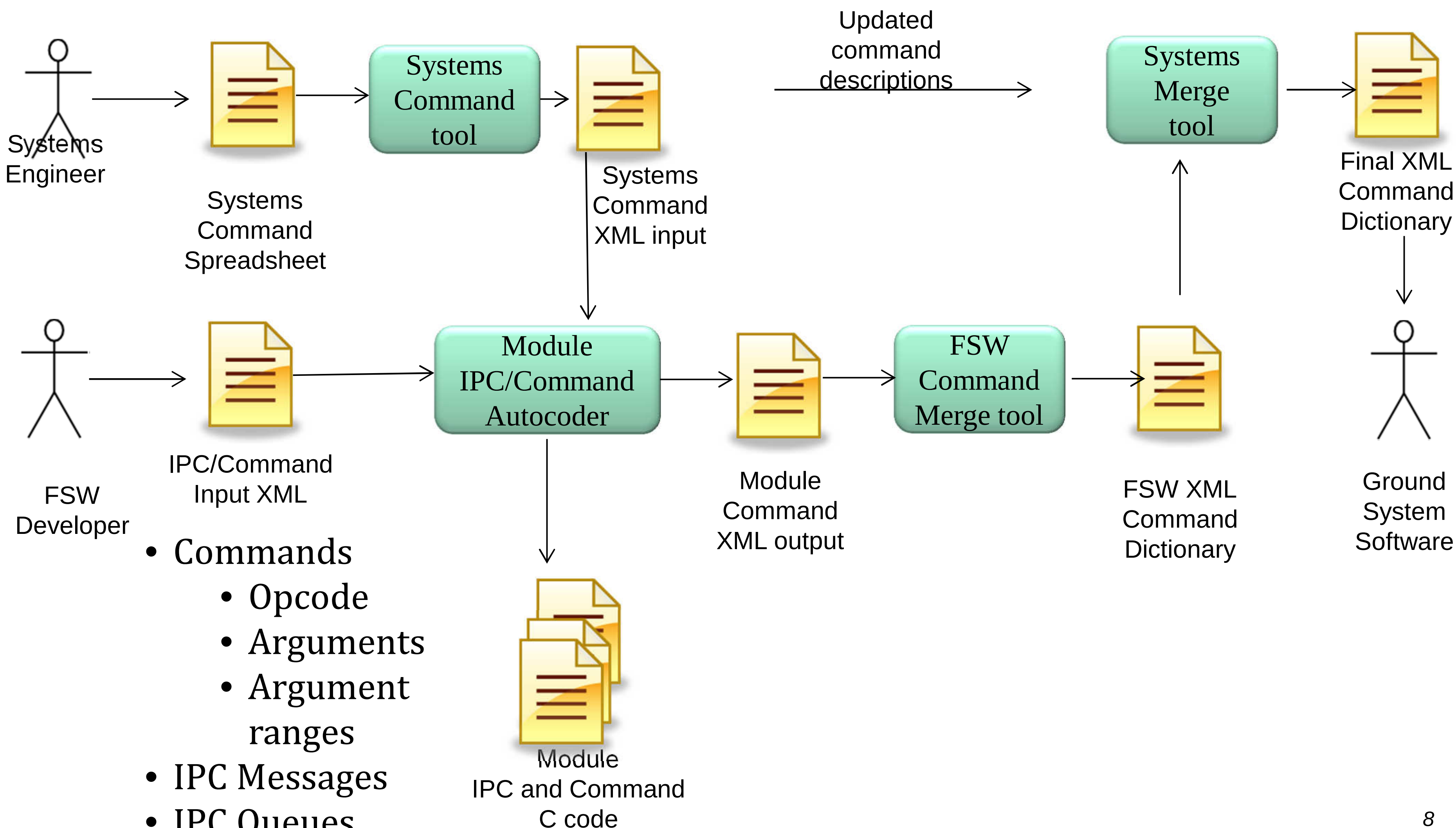
SMAP	Raw KLOC	Physical KLOC	Logical KLOC
Handwritten C	490	252	155
Autogenerated C	142	117	95
Autogenerated XML	157	152	118
Total (XML and C)	790	522	368

	MSL	SMAP
Commands	4000	400
EHA	19,600	3400
EVR	26,000	4200
Data Products	600	30

MSL Dictionary Process

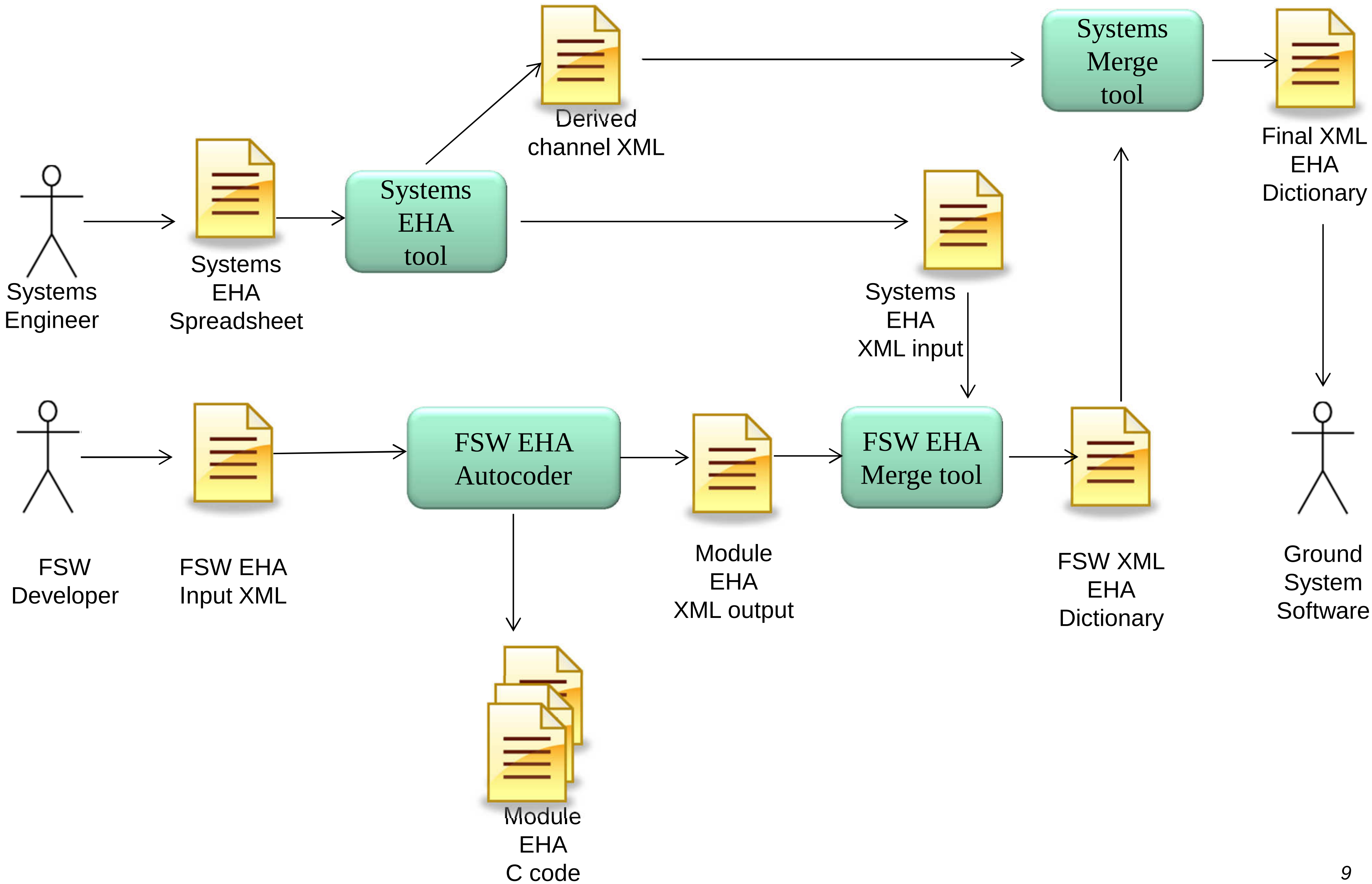
- Systems Engineering "owns" the dictionary
  - Can make dictionary updates that do not affect FSW
- Requirements Sources
  - Command/EHA dictionary specified via spreadsheet by Systems Engineering
    - Converted to XML
  - Functional Description Document
    - Word document detailing behavior specification
    - Included requirements and command/telemetry specifications
  - Requirements
    - Via DOORS Database
    - Included requirements for specific dictionary elements
  - All sources are effectively incomplete (scope, level of detail)
  - FSW could self generate commands/telemetry independent of requirements sources
- All data stored and managed as flat files (Word, Excel, Text, XML)
  - Distributed among a large team
- FSW Change management
  - Items checked into Configuration Management (CM)
    - All autocoder inputs
    - All autocoder tools
    - All handwritten code
  - All autogenerated code was NOT checked into CM
    - Much developer time was spent regenerating code

MSL Autocoder: Command Process



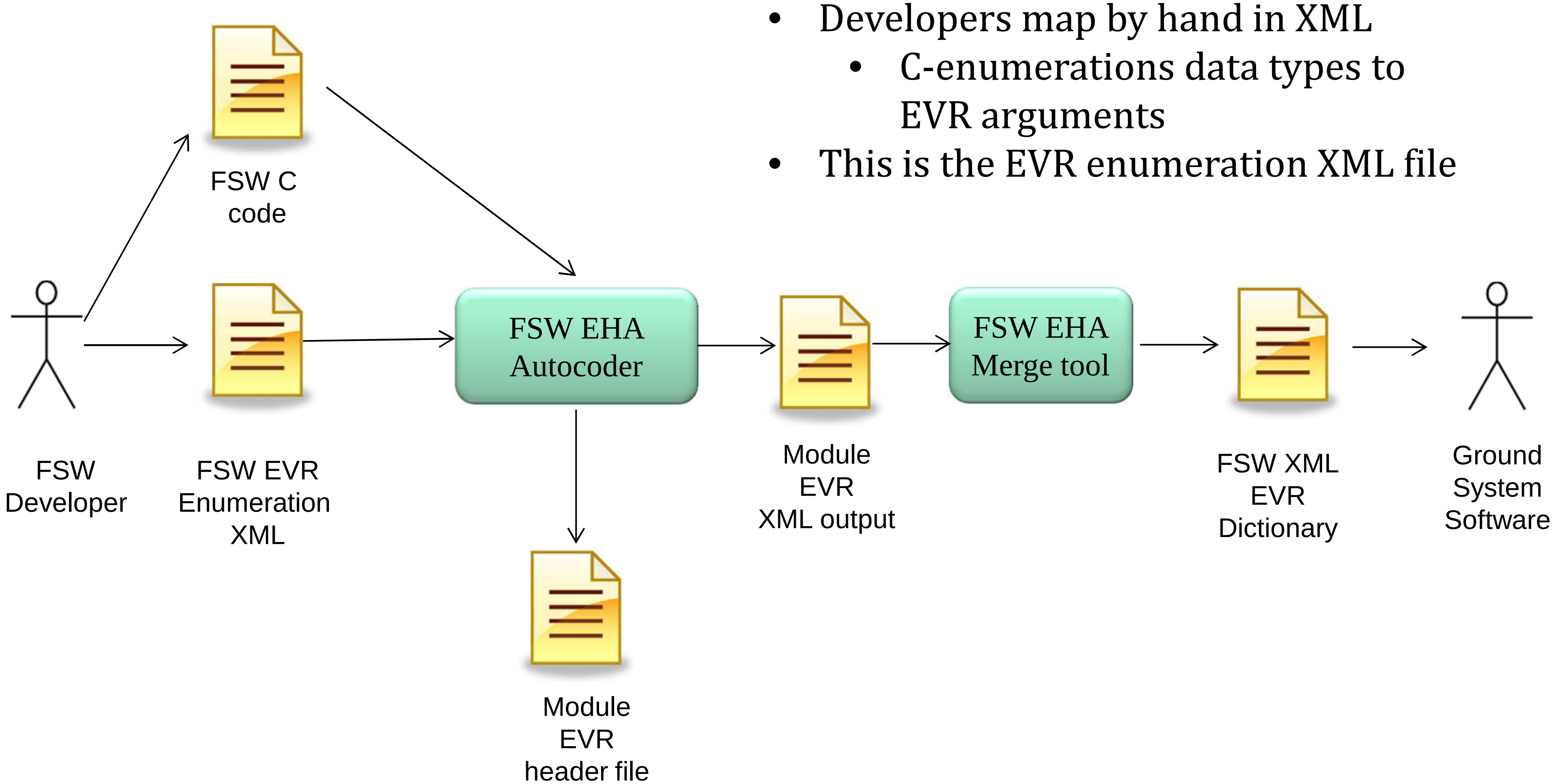
- Commands
    - Opcode
    - Arguments
    - Argument ranges
- IPC Messages
- IPC Queues

MSL Autocoder: EHA Process



MSL Autocoder: EVR Process

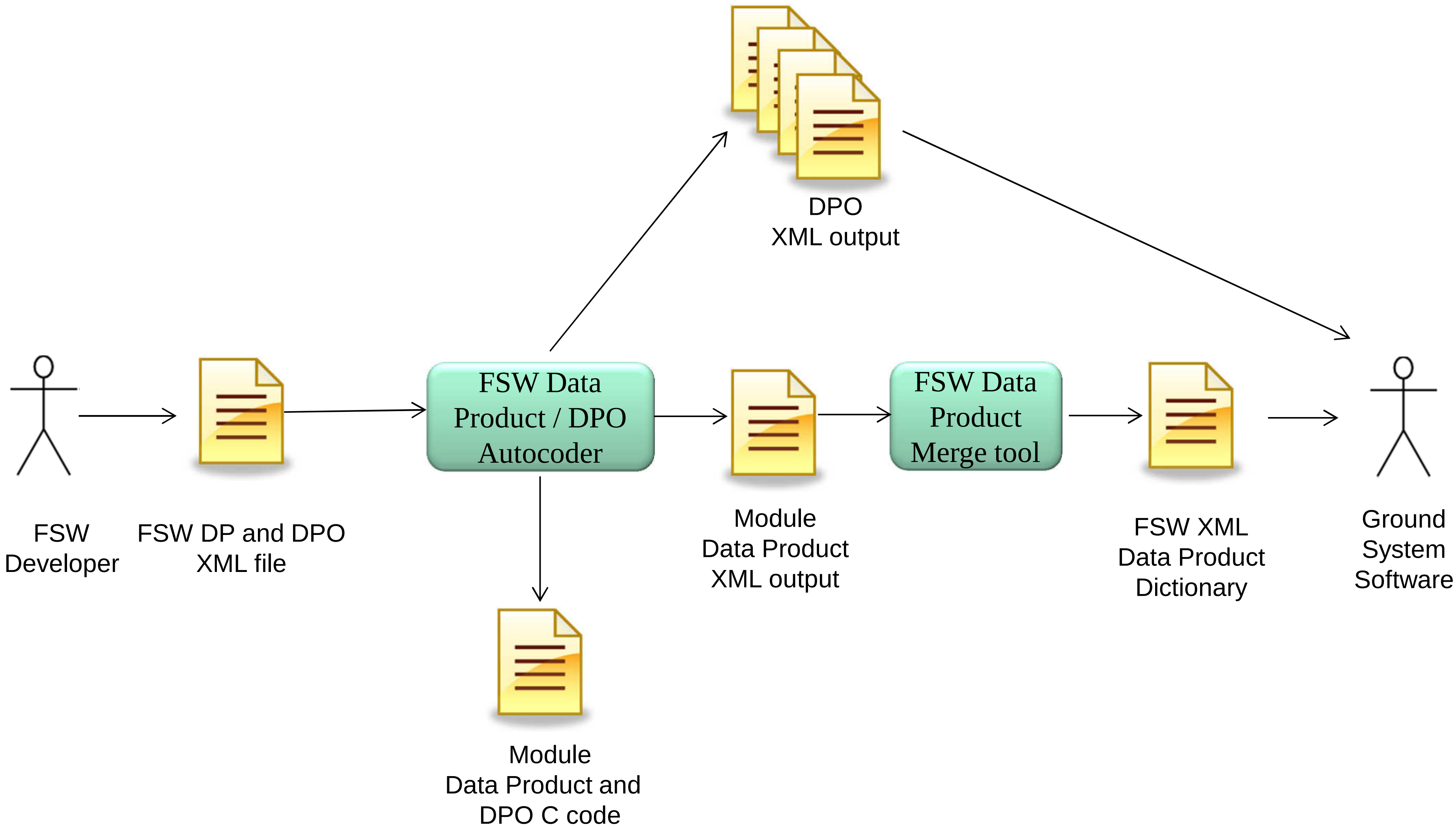
- Developers write EVRs in their C Code
  - An EVR works similarly to a printf
- To specify enumerations
  - Developers map by hand in XML
    - C-enumerations data types to EVR arguments
  - This is the EVR enumeration XML file



MSL Autocoder: Data Products

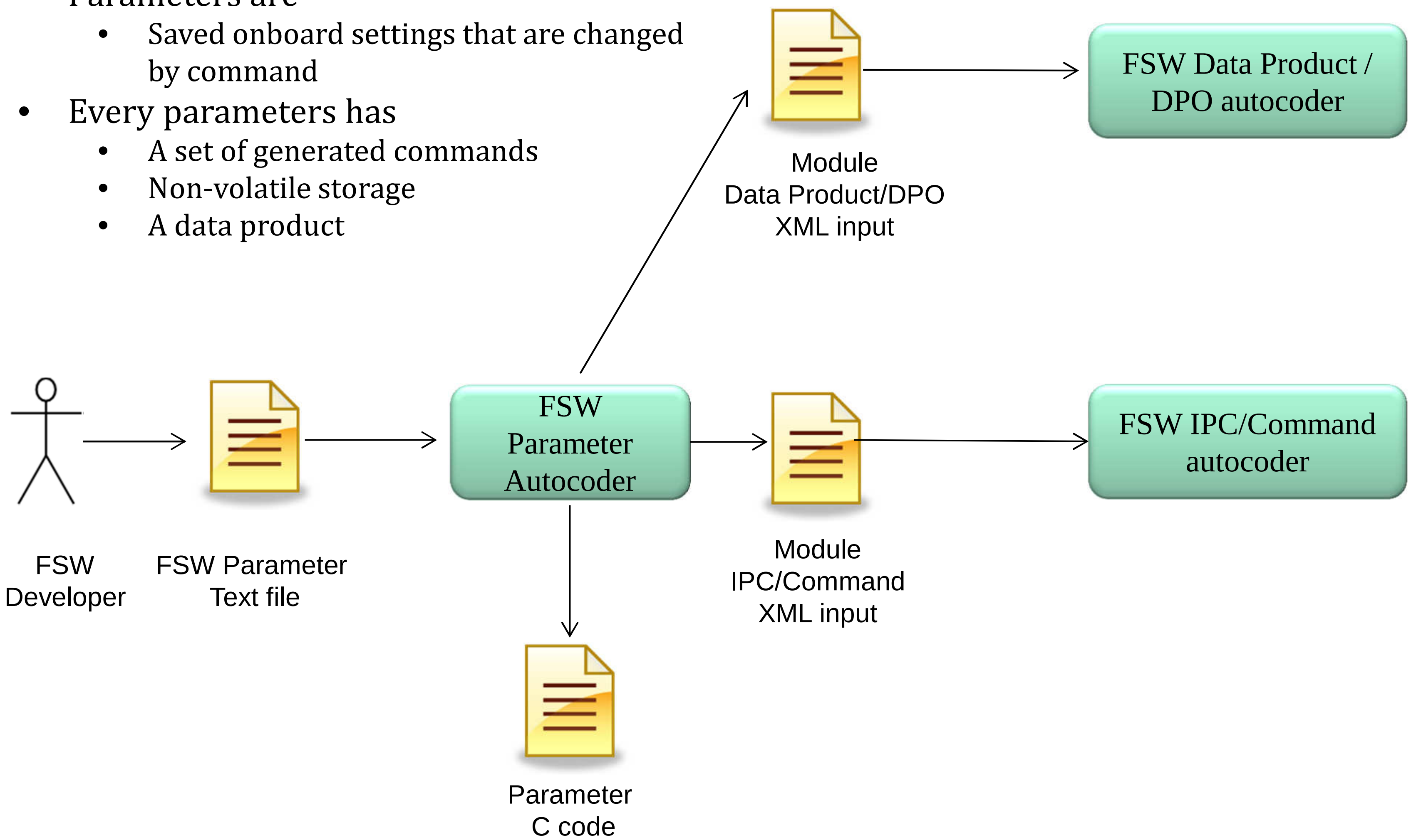
- A data product is a structured binary file onboard the spacecraft
- Given a dictionary, the ground tool can decode any data product into a human readable text form
- To accomplish this on flight and test platforms with difference endian-ness and compilers
  - The encoding, alignment, and endian-ness of all data products is fully specified in a machine-readable consistent way
- Data products can contain multiple Data Product Objects (DPO)
  - Did NOT specify or restrict what DPOs might be in a given data product
- DPOs allow specification of
  - Primitive types
  - Fixed size multidimensional arrays
  - C-like structs
  - Top level variable-sized arrays
  - Strings
- Data product autocoder
  - FSW developers specify data products and DPOs in XML
  - The DP autocoder generates C code to marshal C data structures to data products
    - Performs packing, byte swapping across platforms
- XML representation
  - All data products names/ids are merged into one XML
  - Each DPO is kept separately in its own XML file in the final dictionary

MSL Autocoder: Data Product Process



MSL Autocoder: Parameter Process

- Parameters are
  - Saved onboard settings that are changed by command
- Every parameters has
  - A set of generated commands
  - Non-volatile storage
  - A data product



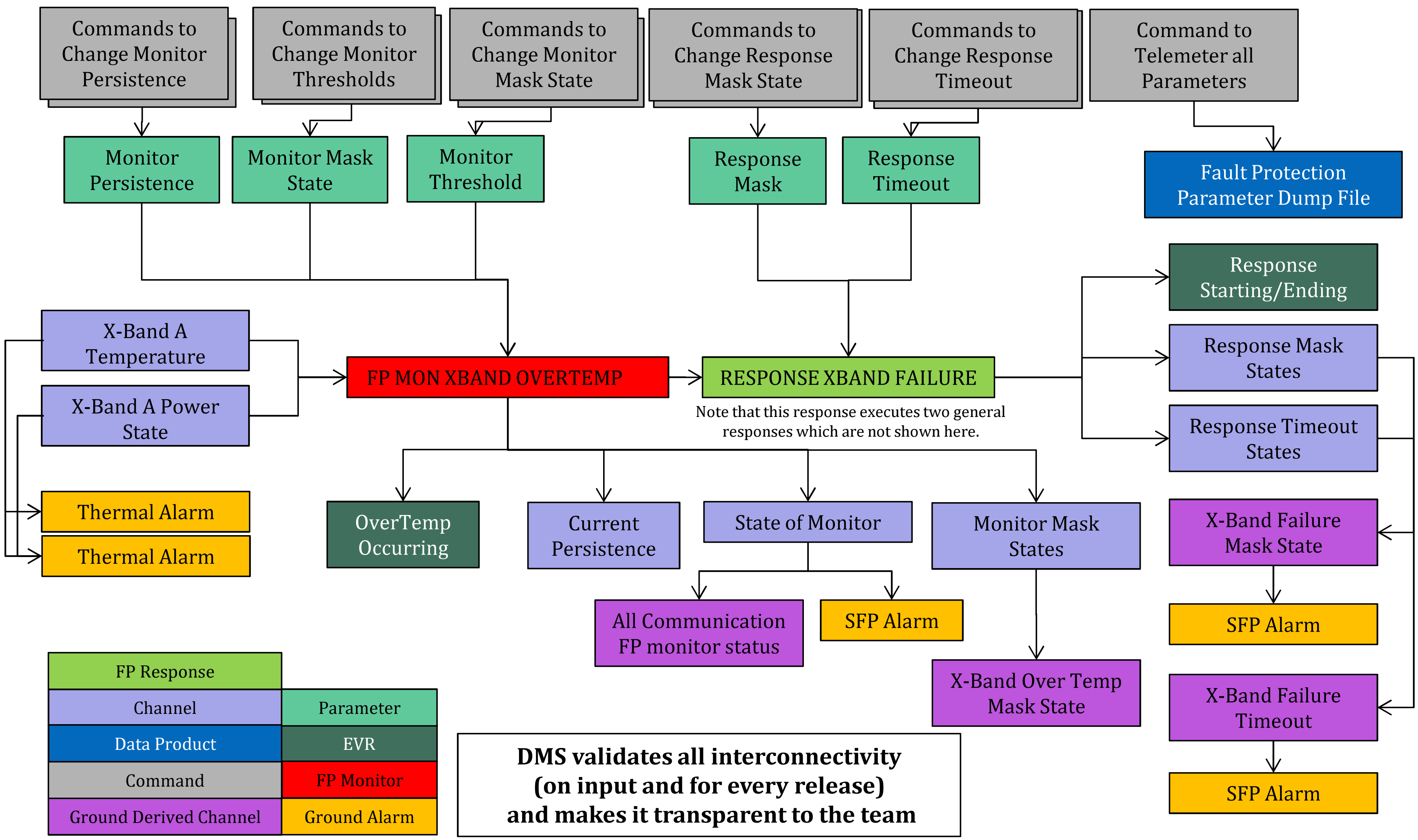
MSL Lessons Learned

- ID Assignment and Locking
  - Late requirement
  - FSW autocoder tools had responsibility
    - IDs were tracked across XML and text files
  - Added implementation overhead in earlier versions of FSW
    - Translation in flight code of locked ids to FSW enumerations
  - Consider tools outside of FSW to track IDs in the future missions
- When to autocode
  - Autocode flight/ground interfaces when
    - The generated code is well defined, repetitive
    - There is a need to synchronize definitions between flight and ground
- Running all the tools to build the dictionary is labor intensive
- Parameters
  - There is no centralized parameter dictionary
    - Caused additional burdens for ground tools tracking parameters over time
- Keeping FSW and Systems in sync on definitions was a challenge
- Requirements sources
  - Requirements in Doors, requirements in Excel, systems command definitions in Excel, FDD word documents
  - Too many sources for the same information (or subsets of the information)
- Overhead
  - Running autocode tools for every checkouts increased build times dramatically

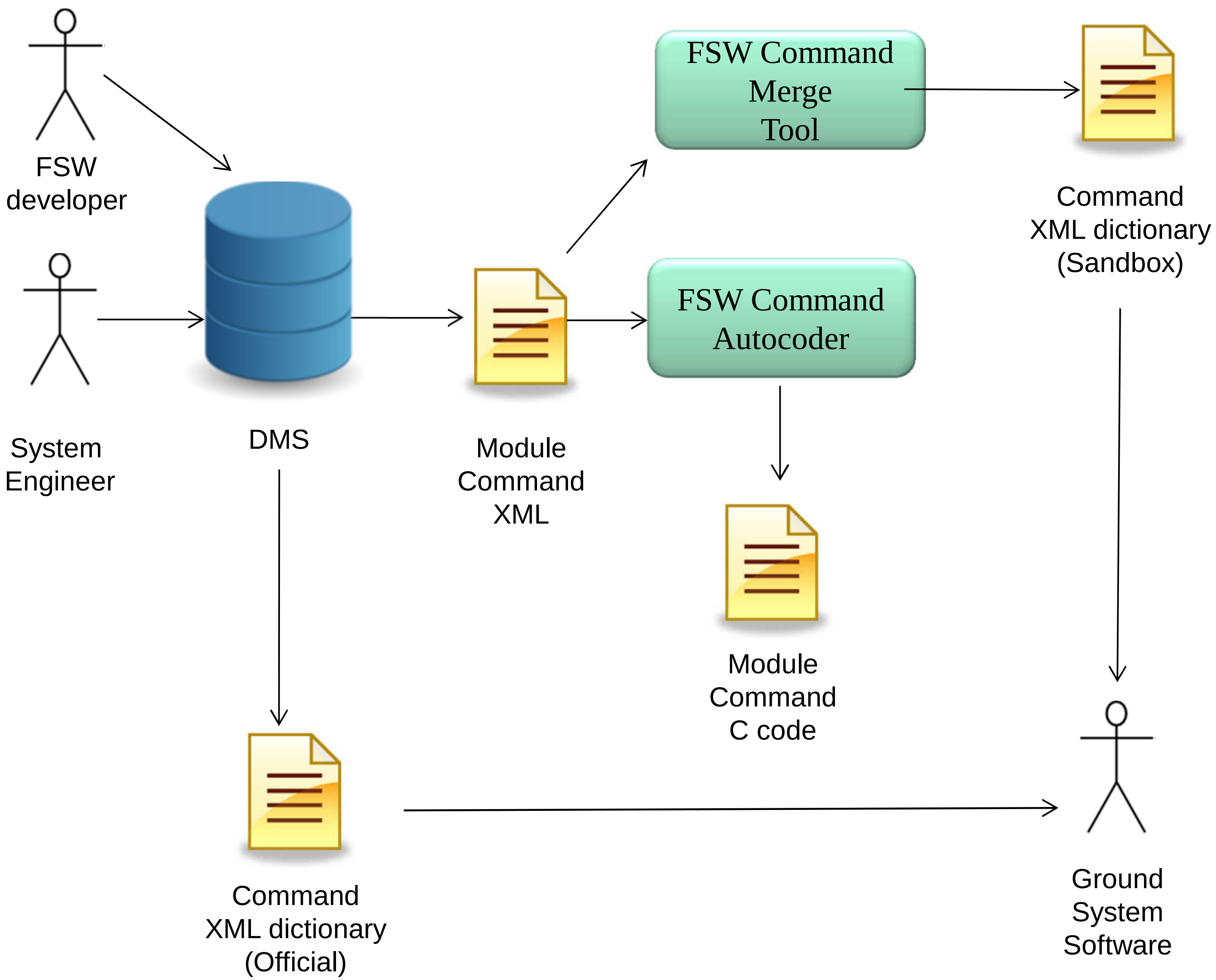
SMAP: Dictionary Process

- Systems Engineering “owns” the dictionary
  - Can make dictionary updates that do not affect FSW
- All data stored in a centralized database and exported as XML
  - SMAP Dictionary process is focused around a web application called DMS (Dictionary Management System).
    - DMS collects input from FSW and Systems engineering, validates, merges, and tracks it.
    - DMS also managed unique IDs of all dictionary elements
  - SMAP elected to incorporate Parameters and Fault Protection Monitors and Responses into the dictionary.
    - This was driven by their interrelation with other dictionary elements and a desire to reduce requirements sources.
- Requirements Sources
  - To streamline requirement sources the SMAP project opted to treat the dictionary as requirements and to centralize them via DMS.
- FSW Change management
  - Items checked into CM
    - All autocoder inputs
    - All autocoder tools
    - All handwritten and autogenerated code

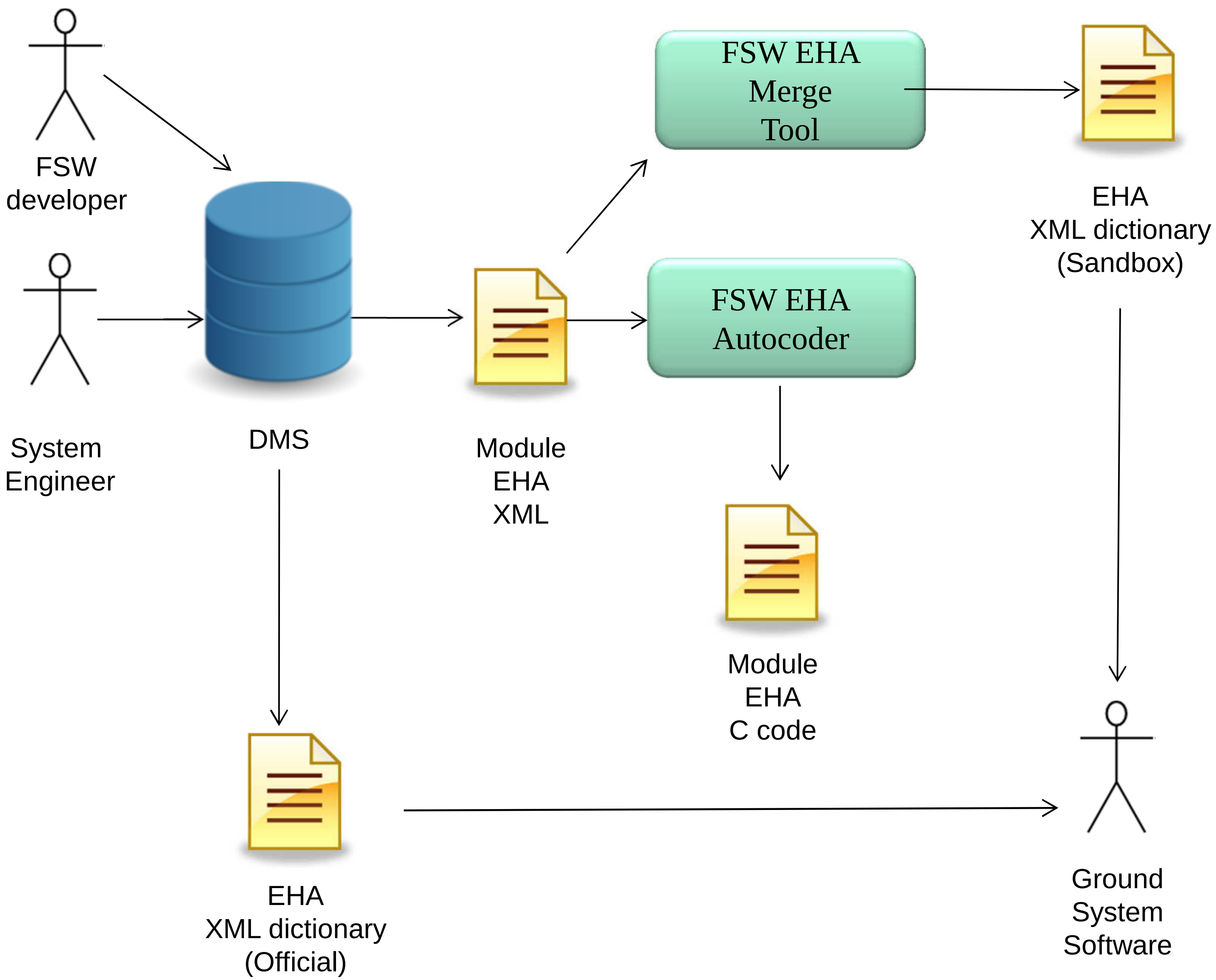
Dictionary Interconnectivity



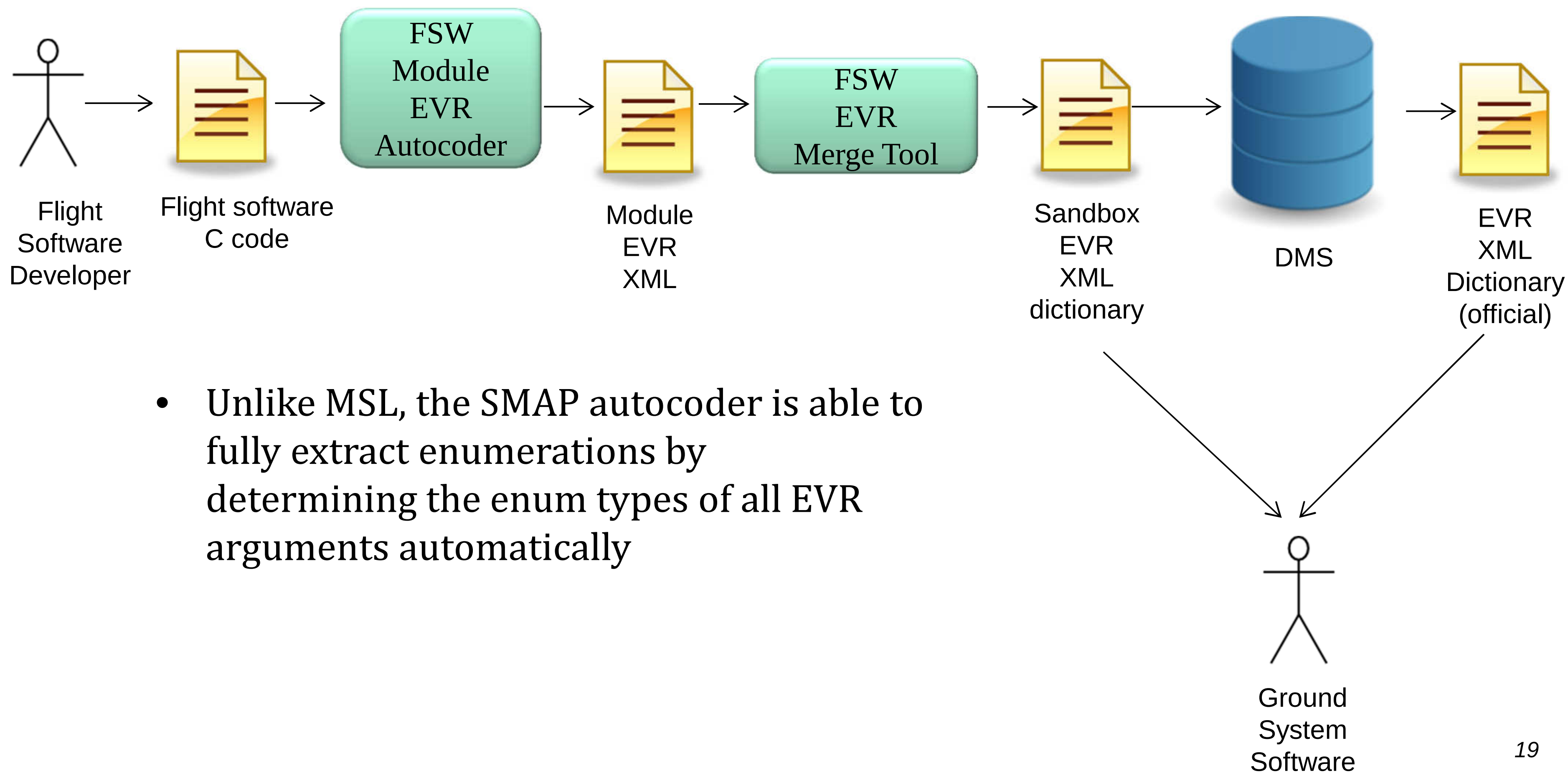
SMAP Autocoder: Command Process



SMAP Autocoder: EHA Process



SMAP Autocoder: EVR Process

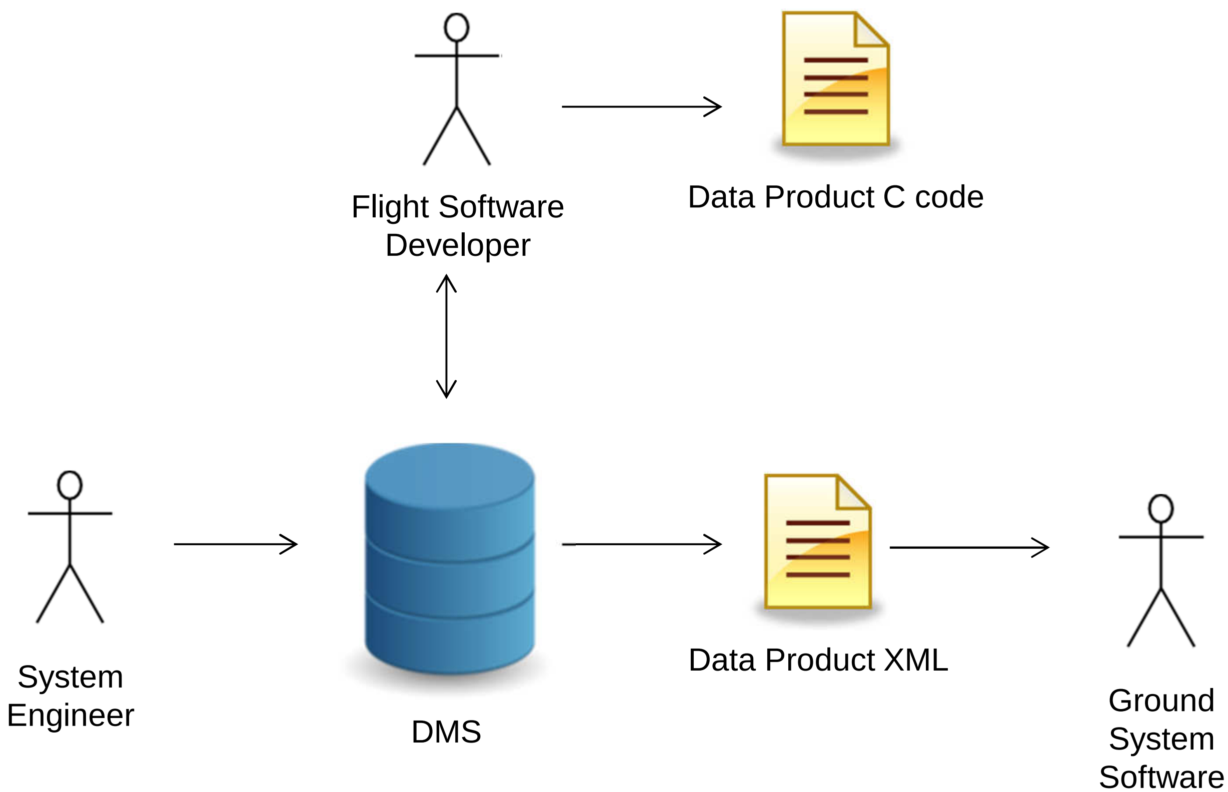


- Unlike MSL, the SMAP autocoder is able to fully extract enumerations by determining the enum types of all EVR arguments automatically

SMAP Autocoder: Data Product Process

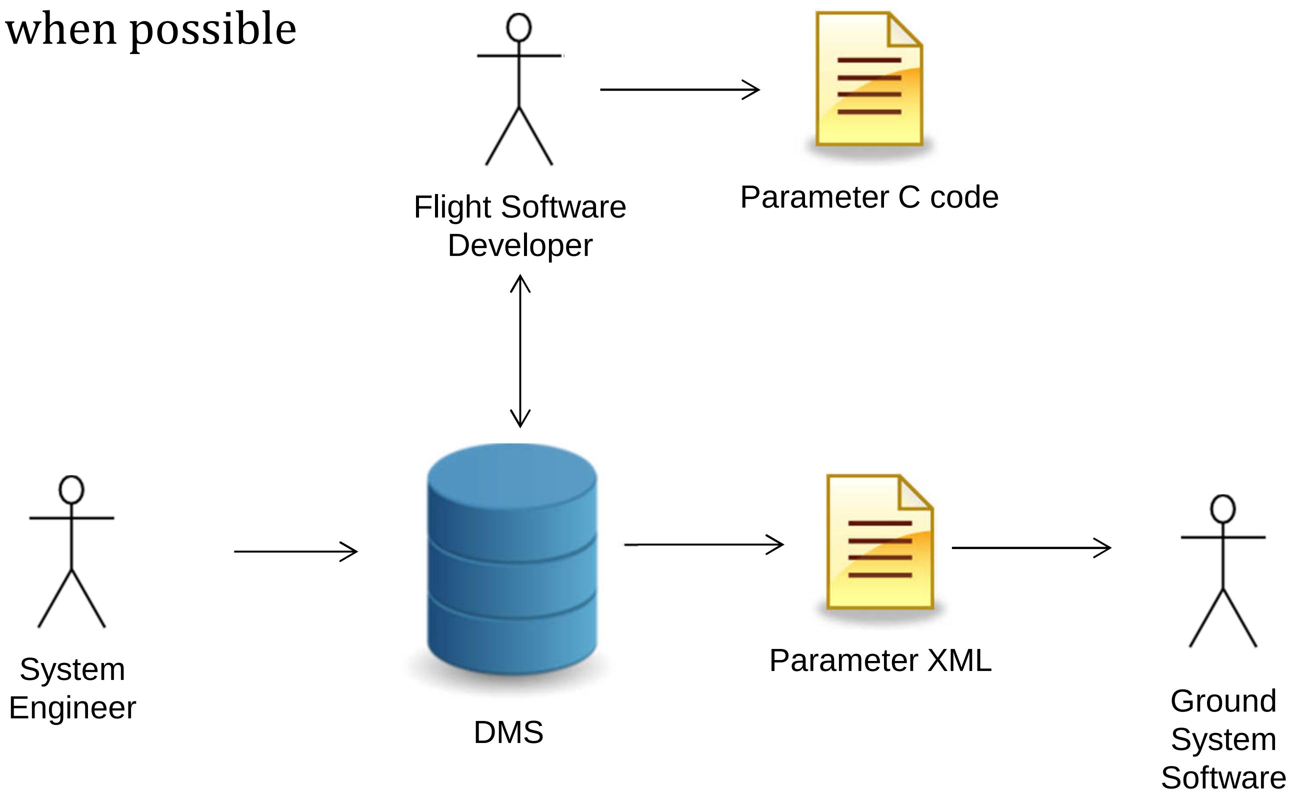
- Like MSL, given a dictionary, the ground tool can decode any data product into a human readable text form
- To accomplish this on flight and test platforms with difference endian-ness and compilers
  - The encoding, alignment, and endian-ness of all data products is fully specified in a machine-readable consistent way
- SMAP allows nesting and repetition
  - Primitive types
  - C-like structs
  - Arrays
  - But there are redundant ways to specify nested structures in XML
- Unlike MSL, SMAP fully specifies data product contents
  - No DPOs
- XML representation
  - All data products names/ids are merged into one XML
  - Each Data Product's contents is kept separately in its own self-contained XML file
- SMAP does not have a data product autocoder
  - Developers manually write code for
    - Data product ids
    - Marshal and byte swap data products

SMAP Autocoder: Data Product Process



SMAP Autocoder: Parameter Process

- Unlike MSL, SMAP does not have a parameter autocoder
- Shows parameter state to the ground via EVR when possible

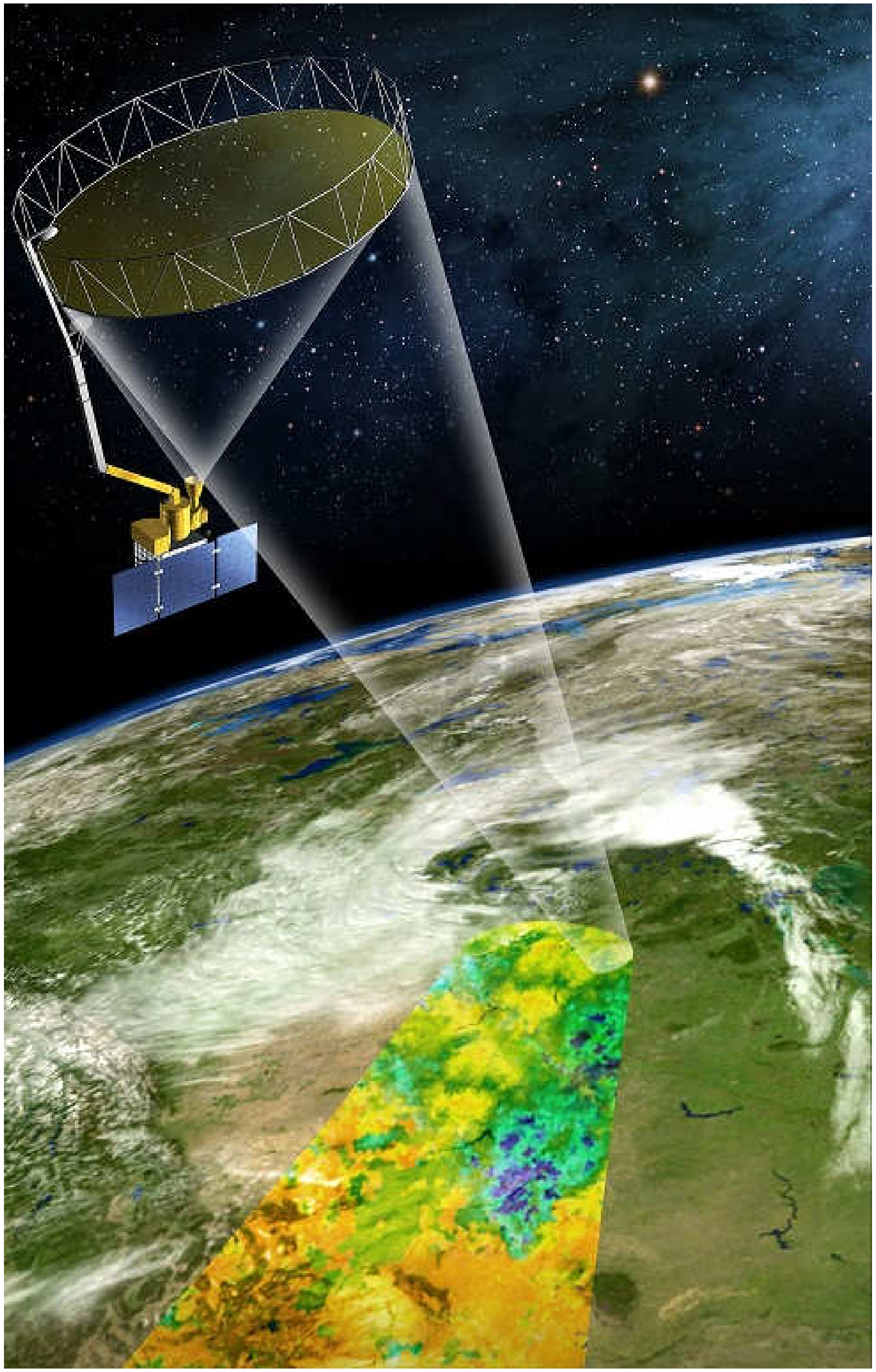


SMAP: Lessons Learned

- Single Source = Big Win
  - Migrating to a single source for all dictionary specification was major improvement.
  - Dramatically reduced mechanical effort required of collecting/merging/analyzing individual files (also reduced error)
  - Enabled the validation of inputs across dictionaries and enhanced rule based validation on inputs (beyond the limits of XML schema)
  - Allowed for rich metadata to follow dictionary elements (including test history)
  - Reduced Systems / FSW dictionary inconsistencies
- Accessibility and Ease of Change brought challenges
  - Configuration Control
    - SMAP dictionaries followed standard JPL project CM/CC which is primarily a paper process.
    - Sync'ing up the paper for a given change with the digital change code could be challenge
  - Work Flow
    - During development inputs would often stream in over multiple weeks
      - What was ready for FSW?
    - Users want more focused view of their work
    - Management wanted to be able to track the work better
    - Systems wanted to know what they could test
- Auto generated code checked in (not regenerated) saved on build time.

Compare Contrast MSL and SMAP

- Single Source (DMS) of information was a major improvement
  - Addressed ID assignment issues, FSW/System Sync Issues
  - Combined with the web application this saved multiple FTE per year
  - Made development progress transparent and helped forecast work to go
  - Enabled easy access to rich meta data (V&V history, cognizant engineer)
  - Validation of input helped improve resulting dictionary (and underlying FSW code)
  - Collapsed several disparate tools into a single tool
- Dictionary as requirements
  - Forced the dictionary to be better (FSW codes to it)
  - Supported the single source
- Autocoding
  - IPC autocoder was useful on MSL, might have been beneficial on SMAP.
  - Data Product autocoder was not needed on SMAP but that was due to scope and number of data products.
- MSL parameters went overboard
  - This had ripple effects across the dictionary (commands, data products, etc)
  - Lack of an up front dictionary resulted in problems tracking them
    - Traceability and visibility issues regarding the default values
- MSL top level Data Product structure was not specified
  - Resulted in difficulty understanding what a given product would contain



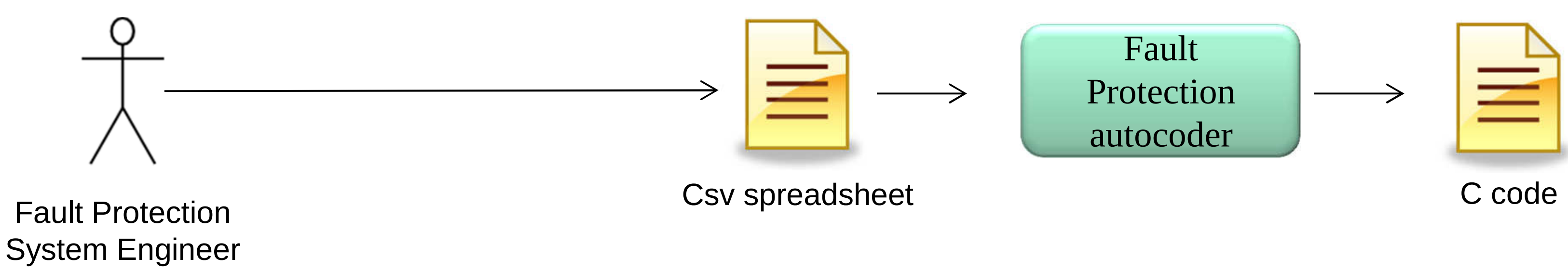
BACKUP

MSL Autocoder: Alarms and Ground Derived Channels

- Channel information independent of flight software
  - Alarms
    - When a channel goes out of range, alert the ops team
  - Derived Channels
- System engineers specify in a spreadsheet
- Autocoder converts alarm, channel spreadsheets into XML for use by the ground system
  - This also needed to validate that the alarm was valid

MSL Autocoder: Fault Protection

- Terminology
  - Monitors
    - Identify a persistent problem
  - System response
    - Makes large system level changes to address a fault condition
    - Enlist multiple modules
- Autocoding fault protection information
  - Only a small subset of fault protection was autocoded
    - Restricted to hardcoded tables and enumerations
      - Enumerations of monitors and responses
      - Arrays mapping monitors to responses
  - System engineers provided a csv text spreadsheet file
  - The autocoder generated C code from the .csv file



Lines of Code

- Raw
  - Count every line once, regardless of its content
- Physical
  - Raw minus blank and comment only lines
- Logical
  - The number of executable statements, as computed by JPL’s SLIC program counter

MSL Autocoder: Commands and IPC Process

- System engineers describe commands in a spreadsheet
  - Specify command restrictions and ranges
  - A systems autocoder converts systems inputs from Excel to XML
- The FSW developer creates XML describing the following per module
  - Commands
    - Opcode
    - Arguments
    - Argument ranges
  - IPC Messages
  - IPC Queues
- The IPC/command autocoder (per module)
  - Generates
    - C Code for decoding commands
    - C Code for sending and receiving IPC messages
    - A module level output command XML
  - Tracks and preserves command opcodes across builds
- The FSW command merge tool concatenates all module command XML, creating the command dictionary

MSL Autocoder: EHA Process

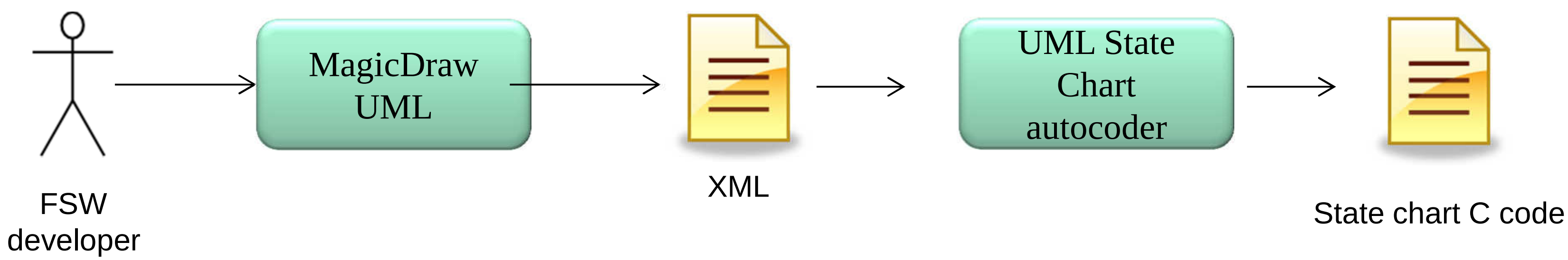
- System engineers describe EHA in a spreadsheet
  - Assign ids and descriptions
  - Create derived channels
    - For the ground, not used by FSW
- The FSW developer creates XML describing the following per module
  - Channel id
  - Data type
- The EHA autocoder combines FSW module XML and system input XML to produce
  - C Code for pushing channels
- The FSW EHA merge tool concatenates all module EHA XML, creating the EHA dictionary
  - Checks that FSW implemented all channels systems requested
    - Using the systems EHA XML input

MSL Autocoder: EVR Process

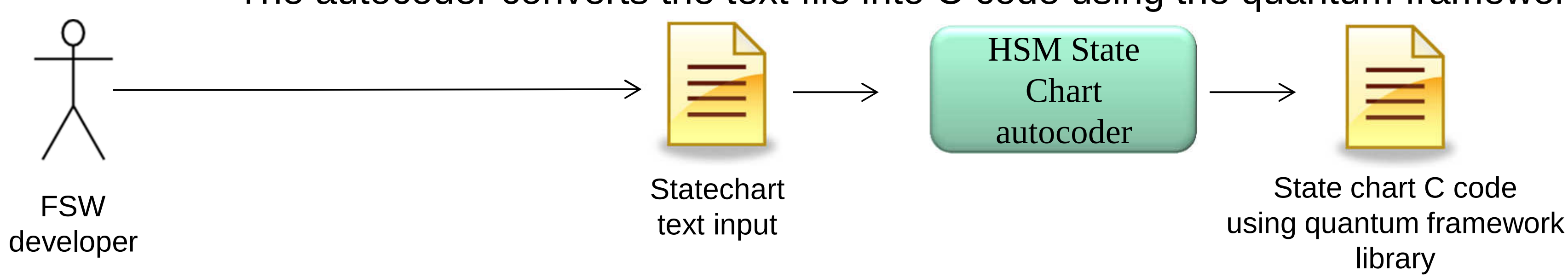
- Developers write EVRs in their C Code
  - An EVR works similarly to a printf
- To specify enumerations
  - Developers map by hand in XML C-enumerations data types to EVR arguments
  - This is the EVR XML file
- The EVR autocoder
  - Extracts EVRs from the C code
    - Data types based on the format specifier
  - Assigns EVR ids
  - Generates a header file with all EVR ids
  - Extracts enumerations and matches them to EVR arguments based on the EVR XML
  - Outputs the module EVR XML file
- An EVR XML merge tool
  - Merges all module level EVR XML files into one large XML file

MSL Autocoder: Statecharts

- MSL had two statechart autocoders
  - Graphical autocoder
    - Developers draw statecharts in the MagicDraw UML graphical editor
    - The autocoder generates C code from the MagicDraw XML file
    - Each event maps to a function
    - Switch statement on the state



  - Text autocoder
    - Uses Samek's Quantum Framework statechart C code library
    - Developers write a text file
    - The autocoder converts the text file into C code using the quantum framework



SMAP Autocoder: Command & EHA Process

- Command process
  - System engineers specify commands in DMS
  - FSW developers export their module commands from DMS as XML
  - The SMAP command autocoder generates code containing command arguments and opcodes only
    - Code is generated per module
    - Module XMLs are merged into a command dictionary usable in sandboxes during development
  - The FSW developer manually writes IPC code
- EHA Process
  - System engineers describe EHA in DMS
  - FSW developers export their module EHA from DMS as XML
  - The SMAP EHA autocoder generates code for pushing EHA

SMAP Autocoder: EVR Process

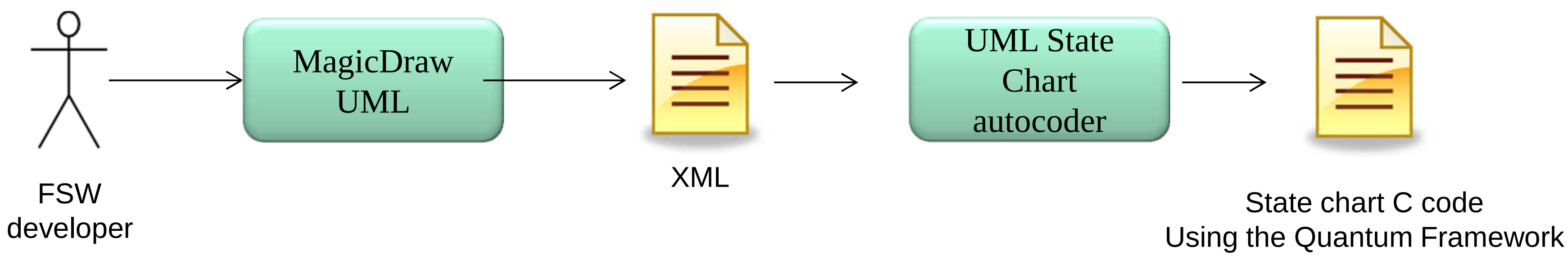
- Developers write EVRs in their C Code
  - An EVR works similarly to a printf
- To specify enumerations
  - Unlike MSL, the SMAP autocoder is able to fully extract enumerations by determining the enum types of all EVR arguments automatically
- The EVR autocoder
  - Extracts EVRs from the C code
  - Unlike MSL, the developer manually specifies an EVR ID
- EVRs are imported into DMS

MSL Autocoder: Parameter Process

- Parameters are
  - Saved onboard settings that can be changed by command
- Parameters are specified in structured text file
  - Containing: Name, Data type, Range, Default value
  - One level of C-like structs and arrays are allowed
  - For large sets of default values, the user can use a .csv file as input
- Every parameters has
  - A set of generated commands for
    - Change the parameter value
      - in RAM or in non-volatile storage
    - Dump the parameter to a data product
  - Non-volatile storage
- The parameter autocoder generates
  - Code to save and read from non-volatile storage
  - XML command definitions for input to the command and data product autocoders
  - Command implementations
- Typical parameter commands change a group of parameters at once

SMAP Autocoder: Statecharts

- Graphical autocoder
  - Developers draw statecharts in the MagicDraw UML graphical editor
  - The autocoder generates C code from the MagicDraw XML file
  - The generated C code uses the Quantum Framework



SMAP Autocoder: Parameter Process

- Unlike MSL, SMAP does not have a parameter autocoder
- Parameters are specified by system engineers in DMS
  - Associated commands are specified in DMS
- FSW developers manually write code that
  - Saves and retrieves parameters from non-volatile storage
    - Uses the specified default value if the parameter cannot be retrieved
  - Implements parameter commands
  - Shows parameter state to the ground
    - Via EVRs when possible
    - With data products otherwise
  - Checks parameter ranges
- DMS exports a parameter dictionary as XML