CCSDS Concept Paper

Fragmentation Data Message

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ABSTRACT

As a new data format in the Navigation Working Group, Mission Operations and Information Management Services Area (MOIMS), the Fragmentation Data Message (FDM) is proposed that contains information relevant to a specific fragmentation event which occurred in-orbit.

Fragmentation data are expected to be exchanged between entities monitoring the space object environment, providers of space situational awareness services, and users of a fragmentation analysis service, among them the potentially affected spacecraft operators.

This paper introduces the Fragmentation Data Message concept, justifies why it should be standardised to simplify data exchange between different entities and provides a draft sample message.

Contents

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Introduction

This document is a Concept Paper for the Consultative Committee for Space Data Systems (CCSDS) [1]. It is intended for consideration by the MOIMS Navigation Working Group as a new area in which a standard data exchange message is needed.

Satellite operators exchange several types of messages already covered by CCSDS standards, covering orbits (OEM, OMM, ODM), tracking observations (TDM), attitude state (ADM) and conjunctions (CDM). However, currently no standard covering fragmentation events exists. A system observing the space environment and determining the orbits of the objects encountered (the existing and planned space surveillance systems) can in some cases determine if detected debris is coming from a fragmentation event. The risk increase for affected orbit regions can then be assessed and the appropriate warnings issued.

Until the end of 2022 there have been 635 confirmed in-orbit fragmentation events. Figure 1 shows an overview of the number of fragments released (the coloured bubbles) as a function of event type (x axis) and time from the launch (y axis). Figure 2 shows the number of fragmentation events per year, as a function of the fragmentation event year (a) and launch year (b). The total number of tracked fragments from all the events is well over 10,000; Figure 3 shows the total number of tracked fragments released per 5-year bin (the different colours are for the cause of the event). The 2020-2025 bin is ongoing and the number of fragments will, very likely, increase. The large peak in the 2005-2010 bin is due to the two largest fragmentation events tracked (the Iridium 33-Cosmos 2251 collision and Fengyun 1C ASAT) happening in 2009 and 2007 respectively. Fragments released in these events are the main cause of spacecraft close approaches and resulting collision avoidance manoeuvres, if close approaches between active satellites are excluded. For example, over 50% of the CDMs issued for Sentinel 1A between November 2015 and April 2017 were caused by fragments from the aforementioned Iridium/Cosmos collision and Fengyun 1C ASAT test [3].

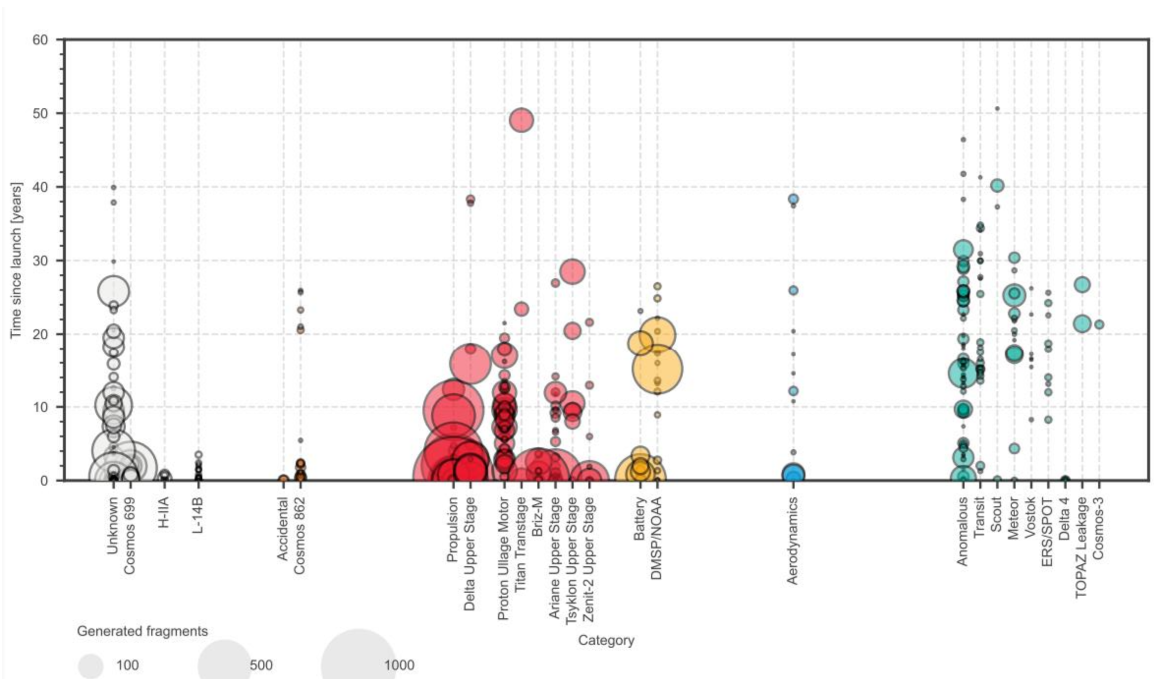
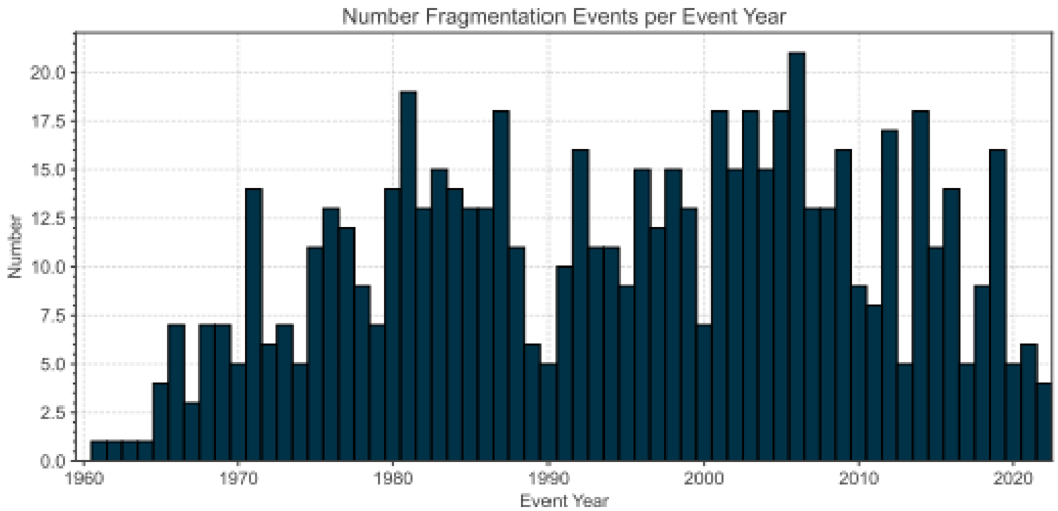
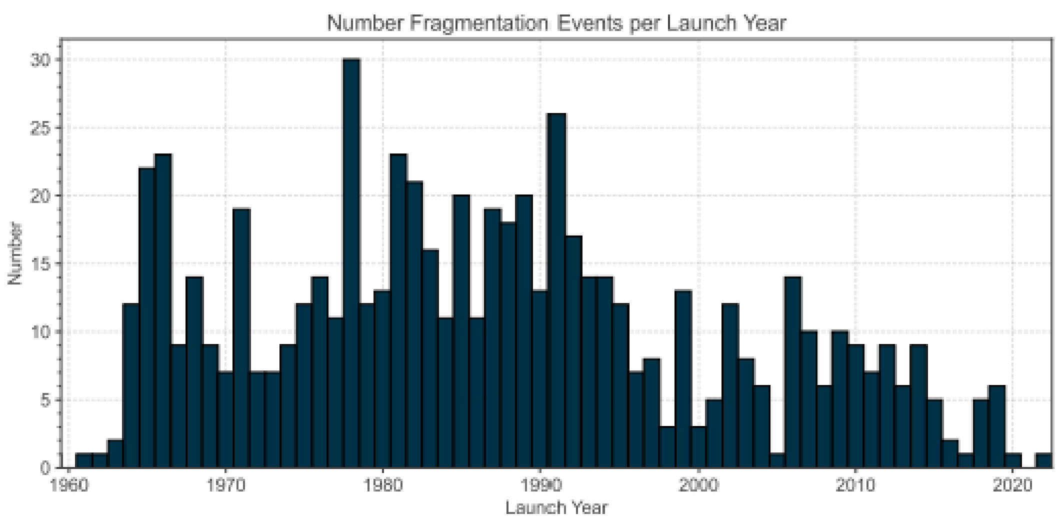


Figure 1 - Number of fragments released as a function of time from the launch (y axis) and event type (x axis), as of October 2023 [2].



(a) Number of fragmentation events per event year.



(b) Number of fragmentation events per launch year.

Figure 2 - Number of fragmentation events per event (a) and launch (b) year as of October 2023 [2].

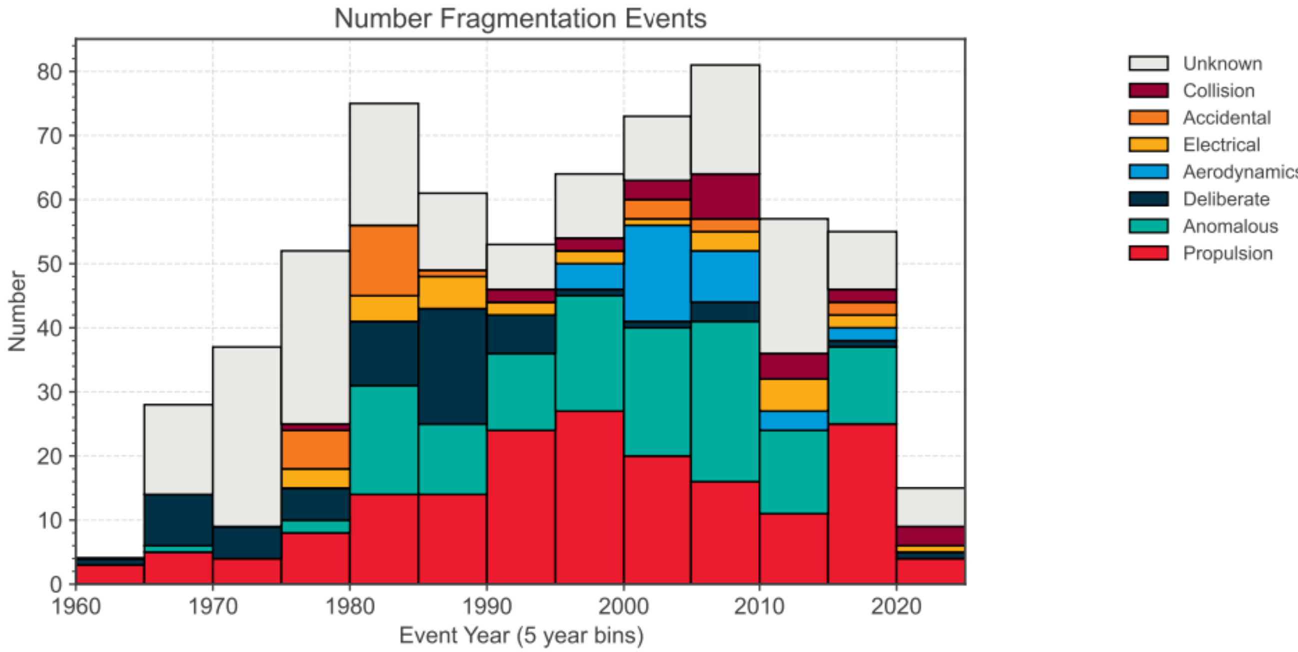


Figure 3 - Total number of fragments released per 5-year bin (as of October 2023, the 2020-2025 bin hence ongoing).

The proposed Fragmentation Data Message (FDM) contains information related to one specific in-orbit fragmentation event of one progenitor object. The latter can be either a spacecraft, a launch vehicle stage, mission-related object or even debris suffering a breakup

Standardisation is needed because:

- no current fragmentation-related standard covers the needs of space surveillance systems, mainly to know how to schedule and where to point sensors to obtain measurements of a fresh breakup cloud and derive good assessments of relevant breakup characteristics;
- fragmentation events are one of the main drivers of collision risk for operational spacecraft;
- standardising the data exchange format would make fragmentation information easier to use by the interested entities (data acquisition, analysis, operations) and enable the set-up of services based on space surveillance data;
- standardising the data exchange would allow more entities to easily and consistently provide fragmentation analysis information and services; for instance, an operator could provide it if one of their spacecraft suffers a fragmentation event (e.g. a battery rupture);
- standardising the data exchange format would promote the interoperability of systems and the re-use of software and processes.

Fragmentation data

ESA has already developed multiple tools for fragmentation data analysis:

- the FAS (Fragmentation Analysis System) prototype developed for ESA's Space Safety programme [7]; FAS analyses a catalogue of space objects to identify fragmentation clouds and the event that created them;
- POEM (Program for Orbit Environment Modelling) uses the NASA break-up model to create a fragment cloud and propagates it to create a snapshot at different epochs [3];
- BUSTER (Break-Up Simulation Tool and Estimation of Risk) uses the fragmentation clouds created by POEM, superimposes them on the background MASTER debris population [8], and estimates the risk increase in the affected regions [3].

Examples of data produced by the above tools are:

- identification of the progenitor object (name, International designator, catalogue identifier, CDM information);
- identification of potentially related FDMs for other objects involved in that event. In the case of a collision, for instance, there would be (at least) two FDMs each associated with the involved progenitors.
- spatial coordinates of the location where the fragmentation event occurred;
- the spread (in terms of Keplerian elements) for the fragmentation cloud
- the type and energy source of the fragmentation event (collision, on-board propellant, pressurant, battery pressurised vessel, etc.);
- number of fragments generated: total number, total number in orbit, estimated, tracked, observed, catalogued, etc.;
- minimum size of detected/catalogued/simulated fragments;
- related observation system(s) which was/were involved in obtaining observations
- information about each fragment (ID, detection epoch, etc).

Advantages/disadvantages of the FDM

Advantages of the Fragmentation Data Message include:

- consolidated access to space surveillance data in a common format;
- enables for independent fragmentation analysis and simulation tools validation and comparison;
- allows for easier access to fragmentation related information for users, primarily operators;
- promotes interoperability and the re-use of software and processes;
- is consistent with the current service-oriented vision in the MOIMS area;
- natural extension of the two space situational awareness products the Navigation Working Group has already developed (the CDM and RDM [9]).

Disadvantages of the Fragmentation Data Message include:

- accommodating all the fragmentation related output is challenging and covering every possible use case is considered difficult for analyses;
- adds more workload to the MOIMS Navigation Working group.

Proposed contents

The proposed structure for the FDM follows the other Navigation Data Messages [2,3,4,9] and consists of a header, metadata, and data sections. The data section contains information on the fragments associated with the event.

The header is to contain information about the message itself, such as the creation date, the originator, and the message identifier.

The (meta)data contains few mandatory entries: the fragmentation id, the status of the event (e.g. detected or simulated), the fragmentation event type (collision, deliberate, accidental, etc), the time of the fragmentation event, and the number of fragments generated. They are enough to cover the minimum of information, for example a few fragments detected as the results of an explosion.

The (meta)data allows for many optional entries, trying to offer enough flexibility while at the same time avoiding the use of user-defined parameters. The optional entries include: the location of the fragmentation event, the parameters used in the propagation of orbit states of the fragments, and information about the previous and next FDM to be issued for the same fragmentation event.

The data section is divided into two blocks, each containing information on one fragmentation cloud. These blocks contain:

- KVN lines with general information about the cloud: progenitor and its pre-fragmentation physical properties, granular control over the number of fragments in the cloud (catalogued, catalogued and still in-orbit, tracked, observed, simulated, etc.), the distribution of orbital elements in the cloud, and the epoch at which the above were valid.
- optional data lines with information for each fragment associated with the event: COSPAR international designator, catalogue ID (e.g.Satellite Number), epoch of first detection, epoch of assignment to the event, and estimated size.

A sample concept Fragmentation Data Message is provided in Figure 4. The sample message contains one fragmentation cloud, generated by a collision involving two objects. It shows a KVN-formatted message. There are other possible approaches to take with the message, such as creating an XML-only message re-using structures from existing XML NDMs [10].

```
CCSDS_FDM_VERS        = 0.1
CREATION_DATE         = 2019-09-12T08:47:55.0
ORIGINATOR            = ESA SST
MESSAGE_ID            = ESA/SDO/FDM-20190912-555

COMMENT This is a comment at start of the metadata section
COMMENT General fragmentation identification in the metadata
FRAGMENTATION_ID       = ESA-2009-003
FRAGMENTATION_STATUS   = DETECTED
FRAGMENTATION_TYPE     = COLLISION
ENERGY_SOURCE          = KINETIC
DATA_SOURCE = ESA
AFFECTED_ORBITAL_REGIMES = LEO/SSO

COMMENT General metadata to point to the central body, time system, and reference frame
CENTER_NAME            = EARTH
TIME_SYSTEM            = UTC
REF_FRAME              = EME2000

COMMENT Fragmentation epoch, fragmentation location, number of clouds generated, and the related
MESSAGE ID, which has information on the collision partner
FRAGMENTATION_EPOCH    = 2009-02-10T02:14:00
POSITION_X             = 4578.324    [km]
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```
POSITION_Y             = 4578.324    [km]
POSITION_Z             = 4578.324    [km]
CLOUDS_GENERATED       = 2
RELATED_MESSAGE_ID = ESA/SDO/FDM-20190912-556

COMMENT Orbital regimes affected

COMMENT Propagation modelling info - optional if a fragmentation cloud is present
GRAVITY_MODEL          = EGM-96: 36D 36O
ATMOSPHERIC_MODEL      = NRLMSISE-00
SOLAR_FLUX_PREDICTION   = PREDICTED: MLLRT
N_BODY_PERTURBATIONS    = MOON, SUN
SOLAR_RAD_PRESSURE      = GSPM04
EARTH_TIDES            = ESR

COMMENT Previous and next FDM to be issued for the same fragmentation event
PREVIOUS_MESSAGE_ID    = ESA/SDO/FDM-20180613-128
PREVIOUS_MESSAGE_EPOCH = 2018-06-13T09:00:00.00
NEXT_MESSAGE_EPOCH     = 2019-10-30T00:00:00.00

COMMENT General information about the progenitor of the fragmentation cloud
PROGENITOR_NAME         = IRIDIUM 33
INTERNATIONAL_DESIGNATOR = 1997-051C
CATALOG_NAME            = SATCAT
CATALOG_DESIGNATOR      = 24946
PROGENITOR_TYPE         = PAYLOAD
PROGENITOR_STATUS       = OPERATIONAL
PROGENITOR_OWNER        = IRIDIUM SATELLITE LLC
PROGENITOR_OPERATOR     = IRIDIUM SATELLITE LLC
PROGENITOR_LOSS         = TOTAL

COMMENT (estimated) spacecraft properties for the progenitor - before the fragmentation
WET_MASS              = 700 [kg]
DRY_MASS              = 550 [kg]
MASS_LOSS             = 700 [kg]
SOLAR_RAD_AREA        = 55  [m**2]
SOLAR_RAD_COEFFICINET  = 0.22
DRAG_AREA             = 37  [m**2]
DRAG_COEFF            = 2.204
RCS                   = 32  [m**2]

COMMENT This is metadata-type information for the fragmentation cloud
EPOCH_TZERO                          = 2019-09-12T00:00:00.00
NUMBER_OF_FRAGMENTS_ESTIMATED_TOTAL     = 3340
NUMBER_OF_FRAGMENTS_ESTIMATED_IN_ORBIT  = 1279
MINIMUM_ESTIMATED_FRAGMENT_SIZE        = 1    [cm]
NUMBER_OF_FRAGMENTS_OBSERVED           = 1724
OBSERVATION_SYSTEM = TIRA
NUMBER_OF_FRAGMENTS_TRACKED            = 1590
NUMBER_OF_FRAGMENTS_CATALOGUED_TOTAL    = 628
NUMBER_OF_FRAGMENTS_CATALOGUED_IN_ORBIT = 344

COMMENT Keplerian elements spread of the fragmentation cloud at EPOCH_TZERO
CLOUD_TYPE = CATALOGUED
DISTRIBUTION_TYPE = LOG-NORMAL
SEMI_MAJOR_AXIS_MEAN  = 7501.750 [km]
SEMI_MAJOR_AXIS_STDEV =  324.034 [km]
ECCENTRICITY_MEAN     =    0.0049
ECCENTRICITY_STDEV    =    0.0084
INCLINATION_MEAN      =   86.40  [deg]
INCLINATION_STDEV     =    5.31  [deg]
RA_OF_ASC_NODE_MEAN   =  134.65  [deg]
```

```
RA_OF_ASC_NODE_STDEV =   56.41  [deg]

COMMENT fragmentation cloud members: fragment number
COMMENT international designator, catalog name, catalogue designator,
COMMENT epoch first observed, epoch first assigned to cloud, estimated diameter [cm]

1   1997-051D    SATCAT 34567 2009-02-10T04:58:00.0 2009-02-10T12:00:00.0 10.0
2   1997-051E    SATCAT 34568 2009-02-10T04:58:00.0 2009-02-10T12:00:00.0 10.0
3   1997-051F    SATCAT 34569 2009-02-10T05:25:00.0 2009-02-10T12:00:00.0 10.0
4   1997-051G    SATCAT 34570 2009-02-10T05:25:00.0 2009-02-10T12:00:00.0 10.0

< ... further data lines ... >

344 NOT_ASSIGNED SATCAT 89012 2020-01-17T02:14:00.0 2020-01-18T12:00:00.0  5.0
```

Figure 4 Sample FDM

What the FDM does not contain

The FDM is not intended to contain detailed orbit/attitude ephemerides, analysis of the fragmentation cause, or the related conjunction information. The aforementioned information can to a large extent be better covered by OEMs [4], AEMs [5] and CDMs [6].

Recommendation

The proposed work fits in with the work performed in the Navigation Working Group in the MOIMS area. If this Concept Paper is approved by the CMC/CESG the Navigation WG charter should be expanded to cover this work.

Risk management strategy

The main technical risk foreseen is the vastly different output data from fragmentation analysis systems, which can lead to disagreement on what should be included in the standard. To mitigate this issue, the number of mandatory data contents in the proposal has been minimised, and a large amount of optional content has been proposed.

The typical management risks with CCSDS standards are a shortage of funding from the agencies and the low time availability of working group members. To mitigate these issues it is proposed that:

- appropriate priority is given to this standard in the Navigation Working Group;
- the work is assigned to the agencies most interested; ESA is interested in leading the development of the standard and in prototyping in collaboration with DLR and ASI.

Conclusion

A CCSDS standard covering fragmentation data is desirable and some member agencies are interested in its development. Developing the standard would make providing fragmentation detection services easier for interested parties.

Abbreviations and acronyms

AEM	Attitude Ephemeris Message
CCSDS	Consultative Committee for Space Data Systems
CDM	Conjunction Data Message
CESG	CCSDS Engineering Steering Group
CMC	CCSDS Management Council
DLR	German Aerospace Centre (Deutsches Zentrum für Luft- und Raumfahrt)
ESA	European Space Agency
ESOC	European Space Operations Centre
FDM	Fragmentation Data Message
MOIMS	Mission Operations and Information Management Services
NDM	Navigation Data Messages
OEM	Orbit Ephemeris Message
RCS	Radar Cross-Section
RDM	Re-entry Data Message
SSA	Space Situational Awareness
SSN	Space Surveillance Network
WG	Working Group

References

[1] Procedures Manual for the Consultative Committee for Space Data Systems. CCSDS A00.0-Y-9. Yellow Book. Issue 9. Washington, D.C.: CCSDS, November 2003.

[2] Space Environment Report. Issue 7.1. Darmstadt: ESA, September 2023.

[3] Braun, Vitali, et al. *Analysis of break-up events*. Proceedings of the 7th European Conference on Space Debris. 2017.

[4] Orbit Data Messages. Recommendation for Space Data System Standards, CCSDS 502.0-B-2. Blue Book. Issue 2. Washington, D.C.: CCSDS, November 2009.

[5] Attitude Data Messages. Recommendation for Space Data System Standards, CCSDS 504.0-B-1. Blue Book. Issue 1. Washington, D.C.: CCSDS, May 2008.

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[9] Re-entry Data Message. Draft Recommendation for Space Data Systems Standards, CCSDS 508.1-R-1. Red Book. Issue 1. Washington, D.C.: CCSDS, June 2018.

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