Multiscale Electrophysiology File Format

Feature	Characteristics
Format	• One file per channel • 24 bit resolution • Independent channel frequencies permitted • Any time series data can be encoded (e.g. transforms of original data)
Compression	• Decreased data storage • Increased network transfer speeds • Variable compression block size permitted • Separate sampling rates for each channel can reduce data volume • Lossless • Improved compression ratio with decreased signal variance (e.g. filtering) • Independent blocks allow parallelizable algorithms
Encryption	• AES 128-bit • HIPAA compliant • Sharing of human data does not require de-identification procedures • Dual-tiered encryption scheme allowing differential access to same file • Unauthorized copies have no access to critical recording details (e.g sampling frequency) • Authorized copies can reveal either just recording details or subject data and recording details • Encryption is not required
Access	• Rapid random access via block indices section • Reading / writing algorithm memory allocation facilitated by block byte & sample max header fields • Block and header field alignment facilitates direct variable access after data read • Rapid discontinuity analysis via discontinuity index section

Feature	Characteristics
Analysis	• Separate file for each channel to facilitate parallel processing • Independence of blocks support asynchronous and parallel processing • Increased read/write speeds due to compression • Precalculated file and block min/max to facilitate various analyses (e.g. display)
Redundancy / Damage mitigation	• 32-bit CRC checksum for block corruption • Block independence limits extent of data loss if damage occurs • 8-byte block alignment can facilitate file recovery if damage results in alignment loss • Block time duplicated in block header and block indices section • Entire block indices section can be reconstructed from data section, if needed
Time	• Discontinuity flag • uUTC time provides globally accurate date & time of day to microsecond resolution • uUTC time is easily converted to UTC time for use with standard Unix / Posix time functions
Events	• Stored in XML format to facilitate parsing, display, and import to databases • Novel event types readily accommodated by XML
Support	• Open source (Apache software license) • Freely available C, Matlab, & Java functions

Multiscale Electrophysiology File:

- Contains EEG data of a single channel in lossless compressed, optionally encrypted format.
- Identified with the ".mef" file extension.
- EEG data are written in compressed, variable-length blocks.
- The file contains a header, EEG data, and block indices section
- The block indices section contains triplets of times (uUTC time - see below), file offsets, and sample indices of the EEG data in the file.

MEF File Structure
Header
EEG Data
Block Indices
Discontinuity Indices

Multiscale Annotation Format (MAF) File:

- Written in XML.
- Contains session information and event records associated with sample times.
- Identified with the ".maf" file extension.
- There is one event file for all channels.
- Example record types include:
    - Video file synchronization data
    - Spike records
    - Seizure markers
    - Event related study data
    - Sleep stage / behavioral state
    - Miscellaneous notes

Data Type Definitions:

Type Name	Description
ui1	1 byte unsigned integer
si1	1 byte signed integer
ui2	2 byte unsigned integer
si2	2 byte signed integer
si3	3 byte signed integer, range $-(2^{23} - 2)$ to $+(2^{23} - 2)$: In two's complement format: sign extend the most significant bit to create an si4. The value -2^{23} (-8,388,608) is reserved to represent NaN (undefined value). Negative infinity is represented by $-(2^{23} - 1)$, positive infinity by $+(2^{23} - 1)$
ui4	4 byte unsigned integer
si4	4 byte signed integer
sf4	4 byte signed floating point number
si8	8 byte signed integer
sf8	8 byte signed floating point number
$(n)	zero-terminated string of length "n" bytes (not including terminal zero)

Header Encryption:

- The header begins with a series of unencrypted bytes, including two text fields and a series of numeric values defining the file's format and characteristics.
- The remainder of the header can be encrypted with "subject" & "session" passwords. Encryption is not required, and the subject and session encryptions can be used together or individually. If both encryptions are used, the session password is stored in the subject-encrypted header block.
- The passwords are zero-terminated strings with a maximum 15 character limit.
- The subject password is used to encrypt subject identifying information and (if session encryption is used also) access the session password stored in the header for session decryption.
- The session password decrypts all technical information related to the EEG recording session.
- The encryption / decryption algorithm is the 128-bit Advanced Encryption Standard (AES). [http://www.csrc.nist.gov/publications/fips/fips197/fips-197.pdf], which satisfies the Health Insurance Portability and Accountability Act (HIPAA) 112-bit requirement for symmetric encryption of human data.

Header Alignment:

- Fields in the header have required byte alignments relative to its start.
- 16-byte alignment facilitates encryption/decryption beginning at that offset.
- Other alignment requirements are determined by the data-types: e.g. 8-byte alignment facilitates reading si8 and sf8 data types.

Header Version 2.2

Field	Offset	Size	Type	Contents	Encryption
Institution	0	64	$(63)	institution	None
Unencrypted Text Field	64	64	$(63)	unencrypted text field (general use)	None
Encryption Algorithm	128	32	$(31)	“128-bit AES”	None
Subject Encryption Used	160	1	ui1	1 if subject encryption used, 0 if not	None
Session Encryption Used	161	1	ui1	1 if session encryption used, 0 if not	None
Data Encryption Used	162	1	ui1	1 if session encryption applied to statistical model in block header, 0 if not	None
Byte Order Code	163	1	ui1	0 ==> big-endian 1 ==> little-endian	None
Header Major Version	164	1	ui1	numeric value: 2	None
Header Minor Version	165	1	ui1	numeric value: 2	None
Header Length	166	2	ui2	length of header in bytes	None
Session Unique Identifier	168	8	ui1	8 numeric values (0-255) that are shared by all mef, and event files representing a particular recording session (zeroes if not entered)	None

Field	Offset	Size	Type	Contents	Encryption
Subject First Name	176	32	$(31)	subject first name	Subject
Subject Middle Name	208	32	$(31)	subject middle name	Subject
Subject Last Name	240	32	$(31)	subject last name	Subject
Subject ID	272	32	$(31)	subject ID	Subject
Session Password	304	16	$(15)	session password (15 character limit)	Subject
Subject Password Validation Field	320	16	ui1	Pascal-style string encoding subject password, terminal unused bytes random	Subject
Timestamp Adjustment Offset	336	8	si8	uUTC timestamp adjustment. This entry is added to all timestamps elsewhere in the file to adjust timestamps. (see below)	Subject
Protected Region	344	8		discretionary	unspecified
Session Password Validation Field	352	16	ui1	Pascal-style string encoding session password, terminal unused bytes random	Session
Number of Entries	368	8	si8	total recorded samples in file	Session
Channel Name	376	32	$(31)	channel name	Session
Recording Start Time	408	8	si8	time in uUTC time format (see below) 0 indicates no entry	Session

Field	Offset	Size	Type	Contents	Encryption
Recording End Time	416	8	si8	time in uUTC time format (see below) 0 indicates no entry	Session
Sampling Frequency	424	8	sf8	sampling frequency -1 indicates no entry	Session
Low Frequency Filter Setting	432	8	sf8	high-pass filter setting -1 indicates no entry	Session
High Frequency Filter Setting	440	8	sf8	low-pass filter setting -1 indicates no entry	Session
Notch Filter Frequency	448	8	sf8	notch filter setting 0 indicates no notch filter -1 indicates no entry	Session
Voltage Conversion Factor	456	8	sf8	microvolts per sample unit 0 indicates no entry negative values indicate voltage values are inverted	Session
Acquisition System	464	32	$(31)	name of acquisition system	Session
Channel Comments	496	128	$(127)	channel comments	Session
Study Comments	624	128	$(127)	study comments	Session
Physical Channel Number	752	4	si4	physical channel number during acquisition -1 indicates no entry	Session
Compression Algorithm	756	32	$(31)	“RED 1.0” (range encoded differences)	Session

Field	Offset	Size	Type	Contents	Encryption
Maximum Compressed Block Size	788	4	ui4	Maximum bytes in compressed block (including block header)	Session
Maximum Block Length	792	8	si8	Maximum number of samples in a decompressed block	Session
Block Interval	800	8	si8	contains microseconds between blocks 0 indicates variable block intervals	Session
Maximum Data Value	808	4	si4	The largest data value in the file	Session
Minimum Data Value	812	4	si4	The smallest data value in the file	Session
Offset to Block Indices Data	816	8	si8	Offset to start of block indices Block indices are stored at the end of the mef file with 8-byte alignment	Session
Number of Block Index Entries	824	8	si8	Total number of entries (triplets) in index data block	Session
Block Header Length	832	2	ui2	length of encoded data block header in bytes	Session
Unused	834	2	ui1	random bytes	Session
GMT offset	836	4	sf4	File recording GMT offset time	Session
Offset to Discontinuity Indices Data	840	8	si8	Offset to start of discontintuity indices Contains block indicies where discontinuity occured	Session

Field	Offset	Size	Type	Contents	En-cryp-tion
Number of Dis-continuity Index Entries	848	8	si8	Number of discontinui-ties in data	Session
Unused	856	92	ui1	random bytes	None
File Unique Identifier	948	8	ui1	8 numeric values (0-255) that are unique to this mef file (zeroes if not entered)	None
Anonymized Subject Name	956	64	$(63)	Anonymized Subject name	None
Header CRC	1020	4	ui4	Cyclically redundant checksum for header data	None
EEG Data Start	1024			RED encoded data blocks	None

Micro-UTC (uUTC) Time Format

- si8 containing the elapsed microseconds since January 1, 1970 at 00:00:00 in the GMT (Greenwich, England) time zone.
- Simply converted to UTC time format (seconds since 1/1/1970 at 00:00:00 GMT)

Timestamp Adjustment Offset

- The Timestamp Adjustment Offset is included in the Subject-encrypted header. If actual timestamps do not need to be encrypted, simply set the Timestamp Adjustment Offset to zero, and all other timestamps in the file will be used as-is.
- If encrypted timestamps is desired, the Timestamp Adjustment Offset can be set to non-zero to obscure the true timestamps. In this manner, time-of-day information can be preserved if the file is used without decrypting the header.

Multiscale Electrophysiology File Data Format

- Data are stored in compressed blocks, compressed with the algorithm specified in the header. In the current version this is the RED (range encoded differences) compression algorithm.
- MEF can encode signed integer data with 24 bits of resolution, giving a dynamic

range of $-(2^{23} - 1)$ to $+(2^{23} - 1)$. The value -2^{23} (-8,388,608) is reserved to represent NaN (undefined values).

- The time interval of the blocks is specified in the block interval field of the header.
- Each data block contain a small header detailed by the compression algorithm, and whose size is specified the block header length field of the file header.
- Each block is indexed by the block indices for random access.

RED Data Compression Format

- Data are stored in compressed independent blocks
- Raw data are differenced. Differences are encoded in a single signed byte. If there is overflow, i.e > +127 or < -127, then a keysample is introduced flagged by the reserved value -128. The three bytes following the keysample flag contain the value of the second data point generating the overflow difference as an si3.
- The differenced data are statistically modeled, the model is stored in the block header.
- Range encoding is used to compress the differences, using the statistical model.
- Blocks are required to be 8-byte boundary aligned.

RED Data Compression Block Format

Field	Size (bytes)	Type	Contents
Cyclically Redundant Checksum	4	ui4	Checksum detects data corruption within the block header and data block
Compressed Block Length	4	ui4	Number of bytes in the compressed block (with boundary alignment), but does not include the length of the block header
Block Start Time	8	si8	uUTC time
Difference Length	4	ui4	Difference data length in bytes
Block Length	4	ui4	Number of data samples encoded in the block
Maximum Data Value	3	si3	The maximum raw value (not difference) encoded in the data block
Minimum Data Value	3	si3	The minimum raw value (not difference) encoded in the data block

Field	Size (bytes)	Type	Contents
Block Flags	1	ui1	Bit 0: 0 indicates no discontinuity, 1 indicates that this block began after a discontinuity in recording, or is the first block in a file. Bits 1-7: reserved.
Block Statistics	256	ui1	Statistical model of difference values for the block. Session password may be used to encrypt this field
Compressed Data	varies	si1	Encoded data

Block Indices Format

- uUTC time, followed by file offset in bytes, followed by sample number.
- Stored at end of EEG data
- 8-byte boundary aligned
- The offset points to the first byte of a compressed block header in the EEG data.

Field	Offset (bytes)	Size (bytes)	Type	Contents
Sample Time	0	8	si8	uUTC time
File Offset	8	8	si8	File offset in bytes, including header bytes
Sample Index	16	8	si8	Index of sample in data file. First sample index is zero.

Discontinuity Indices Format

- Sequential block indices of file discontinuities
- Stored at end of Block Indices data
- 8-byte boundary aligned

Field	Offset (bytes)	Size (bytes)	Type	Contents
Block Index	0	8	si8	number of block starting discontuity

Real-time reading/writing of MEF files

- If a MEF file is still being written to, it can be read, however certain header fields are not guaranteed to be filled in. The Block Index will not be in the MEF file in this case, but it will be written to a separate temporary file instead.
- If the Recording End Time is set to zero, this indicates the MEF file is still being written to.
- The following fields are not guaranteed to be filled in properly until the MEF file is completed: Number of Entries, Recording End Time, Maximum Compressed Block Size, Maximum/Minimum Data Value, Offset to Block Indices Data, Number of Block Index Entries, Offset to Discontinuity Indices Data, Number of Discontinuity Index Entries, Header CRC.
- A temporary Block Index will be written to a separate temporary file. This temporary file will have an extension of .tmp (instead of .mef) and an underscore inserted at the beginning of the file name, but will otherwise be the same filename as the .mef file.
- The contents of the temporary index file is Block Index data (24 bytes per block), corresponding to blocks in the .mef file. There is no header in the temporary index file.
- Once recording to the .mef file is complete, the temporary index file is deleted.
- There is no temporary discontinuity index file.

Multiscale Annotation Format (MAF) XML Session/ Event File Schema

- Transitional file containing information relevant to the acquisition, analysis and persistent storage of EEG annotations.
- XML chosen for flexibility, and general acceptance.
- XML formatted data are considered transient storage.
- Long-term (i.e., “persistent”) storage is handled by a database.
- Database import facilitated by use of XML.
- Custom events and notations can be defined.
- File is easily customized to needs of experiment and lab.

Event File Format

Element	Tag	Contents
XML Declaration	<?xml version="1.0" encoding="UTF-8"?>	None

Element	Tag	Contents
XREDE Document Declaration	<XREDE>	Encompasses all subject, annotation, and channel information
Dataset	<Dataset>	Identifies individual datasets within the MAF file
Subject Information	<Subject>	Any subject-related information that may be persisted.
Episode (Session) Information	<Episode>	Any information pertaining to the recording episode or session that may be persisted.
Task	<Task>	Identifies the source of annotations
Event	<Event>	Any information pertaining to annotations of specific events
Source	<Source>	Information regarding the data sources referred to in the annotation file
Timestamp	<Timestamp>	Information pertaining to particular time points within the file. Timestamps are subordinate to Event elements.

MAF elements maintain a hierarchical relationship, which is strictly enforced. The XREDE declaration encompasses the MAF file's contents and serves to identify the syntax needed to interpret the file. The Dataset element contains the Subject field (as well as its contents), and designates a particular analysis or experiment. The Subject field contains Task and Episode fields, and contains information designating the subject (human or animal) being studied. The Task field contains information regarding the method used to generate annotations in the file, for example, technologist notes during acquisition, physician annotations on review, or output from an event detection algorithm. The Episode field is hierarchically parallel to the Task field, existing as a member of the Subject field, and contains Source and Event fields. Episode is synonymous with session as used in the MEF specification, but Episode is used to maintain compatibility

with the XCEDE (XML-Based Clinical Experiment Data Exchange Schema) developed by the Bioinformatics Research Network (http://www-calit2.nbirn.net/tools/xcede/index.shtm).

Episode or session information pertains to a particular recording session and a particular set of MEF files. The specific MEF files making up the recording Session or Episode are designated by Source fields, which are members of the Episode field. Source fields contain, among other information, the name of the MEF file referenced, and a channel label. Event fields are hierarchically parallel to the Source field as members of the Episode field. Event fields designate events or annotations within the recorded data, and typically contain one or more Timestamp elements, which designate the beginning (onset) and if applicable, end (offset) of an event. The nature of the Event field is designated by the "type" tag within the Event annotation.

This hierarchy is illustrated by the following pseudocode:

```
XREDE Declaration {
    Dataset {
        Subject {
            Task { }
            Episode {
                Source { }
                Event {
                    Timestamp { }
                }
            }
        }
    }
}
```

Subject Information

Syntax: <Subject [parameters]> … </Subject>

Element	Tag	Contents
Subject First Name	`name_first="Firstname"`	Subject's first name.
Subject Middle Name	`name_middle="Middlename"`	Subject's middle name.

Element	Tag	Contents
Subject Last Name	name_last="Lastname"	Subject's last name.
Subject ID Number	Subject_nbr="#####"	Subject's identification number.
Data Directory	data_dir = "/path/"	Local directory containing MEF channels
Dataset ID	DatasetID="#"	Identifies dataset within MAF file to which subject information pertains.

Episode Information

The MAF Episode field is conceptually identical to the Session designation used in the MEF specification. The term "Episode" is used to maintain syntactic compatibility with the XCEDE format, defined by the BIRN.

Syntax: <Episode [parameters]> … </Episode>

Element	Tag	Contents
Institution	institution = "name"	Institution where recordings occurred.
Session Unique ID	uid = "0.0.0.0.0.0.0.0"	Eight-integer, unique ID code separated by decimal points.
Session Recording Start Time	recording_start_time = "1145095591430062"	Beginning of recording session
Time Units	time_units = "uUTC"	Units in which recording start time and other time notations are expressed
Dataset ID	DatasetID="#"	Identifies dataset within MAF file to which episode information pertains.
Subject ID	SubjectID="#"	Identifies subject within MAF file to which episode information pertains.

Event Annotations

Syntax: <Event [parameters]> … </Event>

Element	Tag	Contents
Event type	`type = “event_type”`	Describes the type of event in the current annotation
Episode ID	`EpisodeID="#"`	Identifies episode within MAF file to which event information pertains.
Task ID	`TaskID="#"`	Identifies task within MAF file to which event information pertains.

Timestamps

Syntax: <Timestamp [parameters]/>

Element	Tag	Contents
Onset	`onset = “1082190114028809”`	Gives the onset, or start, of the timestamp, in the time units denoted in the episode tag.
Offset	`offset = “1082190114028809”`	Gives the offset, or end, of the timestamp, in the time units denoted in the episode tag.
Vector	`vector = “1082190114028809, 1082190119119348, 1082190132921644”`	Vectors are stored as type-specific information followed by comma-separated values.

Element	Tag	Contents
Event ID	EventID="#"	Identifies event to which timestamps information pertains.
Source ID	SourceID="#"	Identifies data source within MAF file to which event information pertains.

Source Information

Syntax: <Source [parameters]\>

Element	Tag	Contents
Name	name = “channel1.mef”	Name of MEF file
Label	label = “channel1”	Label used to refer to the current channel
Episode ID	EpisodeID="#"	Identifies episode within MAF file to which source belongs.

Task Information

Syntax: <Task [parameters]\>

Element	Tag	Contents
Name	name = “task_info”	Description or name of task linked to current Dataset.
Dataset ID	DatasetID="#"	Identifies dataset within MAF file to which task information pertains.

Example MAF XML Annotation File:

```
<?xml version="1.0" encoding="UTF-8"?>
<XREDE>
   <Dataset id="1">
```

<Subject DatasetID="1" Subject_nbr="9-999-001" data_dir="/Volumes/Server/EEG_Data/Patient_1/" id="1"
name_first="Firstname" name_last="Lastname">
<Episode SubjectID="1" id="1" recording_start_time="1081883637196616" time_units="uUTC">
<Event EpisodeID="1" TaskID="1" id="1" type="seizure">
<Timestamp EventID="1" SourceID="1" id="1" offset="1082190132044160" onset="1082190114028809" />
<Timestamp EventID="1" SourceID="2" id="2" offset="1082190132044160" onset="1082190114028809" />
<Timestamp EventID="1" SourceID="3" id="3" offset="1082190132044160" onset="1082190114028809" />
<Timestamp EventID="1" SourceID="4" id="4" offset="1082190132044160" onset="1082190114028809" />
<Timestamp EventID="1" SourceID="5" id="5" offset="1082190132044160" onset="1082190114028809" />
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<Timestamp EventID="1" SourceID="23" id="22" offset="1082190132044160" onset="1082190114028809" />
<Timestamp EventID="1" SourceID="24" id="23" offset="1082190132044160" onset="1082190114028809" />
</Event>
<Event EpisodeID="1" TaskID="1" id="10" type="Note: Patient pressed call button">
<Timestamp EventID="10" id="25" onset="1082190116117843" />
</Event>
<Event EpisodeID="1" TaskID="1" id="10" type="artifact">
<Timestamp EventID="10" id="26" onset="1082190605119412" />
</Event>
<Event EpisodeID="1" TaskID="1" id="10" type="spike">
<Timestamp EventID="1" SourceID="18" id="27" onset="1082190674122539" />
<Timestamp EventID="1" SourceID="19" id="28" onset="1082190674122539" />
<Timestamp EventID="1" SourceID="22" id="29" onset="1082190674122539" />
<Timestamp EventID="1" SourceID="23" id="30" onset="1082190674122539" />
</Event>
<Source EpisodeID="1" id="1" label="LAG1" name="LAG1.mef" />
<Source EpisodeID="1" id="2" label="LAG2" name="LAG2.mef" />
<Source EpisodeID="1" id="3" label="LAG3" name="LAG3.mef" />
<Source EpisodeID="1" id="4" label="LAG4" name="LAG4.mef" />
<Source EpisodeID="1" id="5" label="LAG5" name="LAG5.mef" />
<Source EpisodeID="1" id="6" label="LAG6" name="LAG6.mef" />
<Source EpisodeID="1" id="7" label="LAG7" name="LAG7.mef" />
<Source EpisodeID="1" id="8" label="LAG8" name="LAG8.mef" />
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<Source EpisodeID="1" id="10" label="LAG10" name="LAG10.mef" />
<Source EpisodeID="1" id="11" label="LAG11" name="LAG11.mef" />
<Source EpisodeID="1" id="12" label="LAG12" name="LAG12.mef" />
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<Source EpisodeID="1" id="24" label="LAG24" name="LAG24.mef" />
<Source EpisodeID="1" id="25" label="LAS1" name="LAS1.mef" />
<Source EpisodeID="1" id="26" label="LAS2" name="LAS2.mef" />
<Source EpisodeID="1" id="27" label="LAS3" name="LAS3.mef" />
<Source EpisodeID="1" id="28" label="LAS4" name="LAS4.mef" />
<Source EpisodeID="1" id="29" label="LAS5" name="LAS5.mef" />
<Source EpisodeID="1" id="30" label="LAS6" name="LAS6.mef" />
<Source EpisodeID="1" id="31" label="LAS7" name="LAS7.mef" />
<Source EpisodeID="1" id="32" label="LAS8" name="LAS8.mef" />

```
            </Episode>
        </Subject>
        <Task DatasetID="1" id="1" name="user annotations" />
    </Dataset>
</XREDE>
```