Anomaly detection using Unsupervised Machine Learning for Grid computing site operation

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ICEPP regional analysis center

- International Center for Elementary Particle Physics (ICEPP) at U.Tokyo
  - **ATLAS experiment at LHC**, MEG experiment at PSI, R&D for ILC

- ICEPP operates a computing center:
  - Support ATLAS VO in WLCG as Tier2 and provide ATLAS-Japan dedicated resources (local use)
  - ~ 10k CPU cores and ~15 PB disk storage
  - Tokyo Tier2 is the only WLCG site in ATLAS-Japan

- Grid middleware (services):
  - Computing Element: ARC-CE
  - Storage Element: DPM
    - ✓ **One of the biggest DPM site in WLCG**

Regional analysis center

~300 m²

Grid service logs

- “Text logs” produced by the Grid services provide useful information for understanding the status of services
  - Important for a stable and reliable site operation
  - e.g DPM logs at Tokyo Tier2:

Time stamp **Severity** **Message**

```
May 29 14:05:50 lcg-se01 python2[65569]: [0] dmlite Config ConfigFactory : ——— ConfigFactory started. Starting configuration phase. DMLite v1.12.1
May 29 14:05:50 lcg-se01 python2[65569]: [4] dmlite BuiltInAuthnFactory configure :  Key: LogLevel Value: 0
May 29 14:05:50 lcg-se01 python2[65569]: [4] dmlite BuiltInCatalogFactory configure :  Key: LogLevel Value: 0
May 29 14:05:50 lcg-se01 python2[65569]: [4] dmlite ConfigFactory LogCfgParm :  Key: LogLevel Value: 0
May 29 14:05:50 lcg-se01 python2[65569]: [0] dmlite config configure : Setting global log level to :0
May 29 14:05:50 lcg-se01 python2[65569]: [0] dmlite config configure : Processing config directory:/etc/dmlite.conf.d/*.conf
May 29 14:05:51 lcg-se01 xrootd[65478]:  !!! dmlite dome processreq : DN '/C=JP/O=KEK/OU=CRC/OU=ICEPP/CN=host/lcg-se01.icepp.jp' has NOT been authorized.
```

  - Can understand that there is a problem with authentication

→ **Time-consuming tasks for site administrators to monitor and analyze the service logs everyday…**

→ **A support framework to detect anomaly logs has been developed and examined**

Machine Learning approach

- Log analysis using script does not scale for complicated logs
  - > 1M errors are observed for DPM everyday. Which error is real anomaly…?
  - Difficult to set criteria for all possible error logs

→ **Examine Machine Learning approach based on log "similarity"**

- "Unsupervised" Machine Learning is used because:
  - Typical classifications require pre-defined labels, but it is difficult to collect a large amount of anomaly logs that cover all possible anomalies

- Idea of anomaly detection:
  - Text logs → Preprocessing → **Vectorization** → **Clustering**
  - **Aim to detect anomalies in DPM logs in this study**

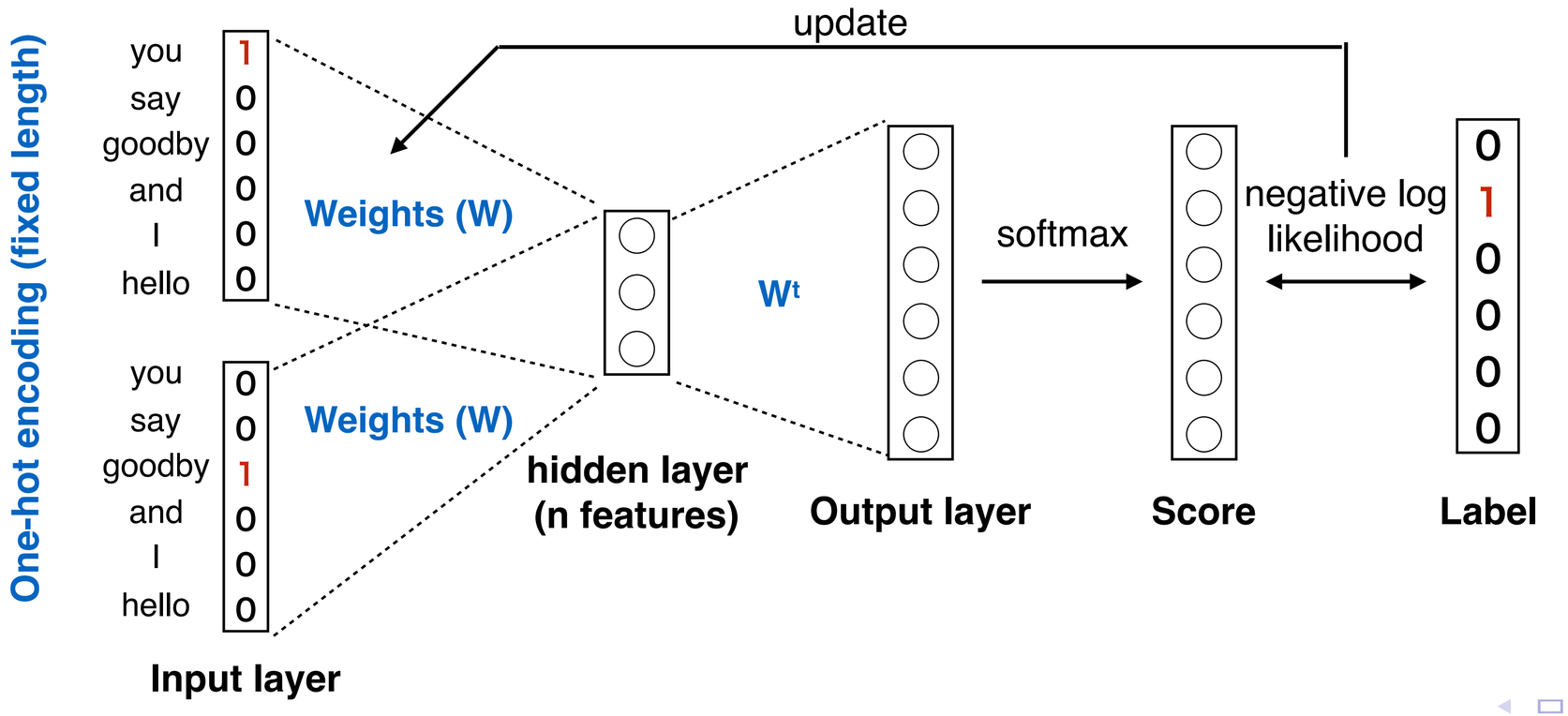
Preprocessing → Vectorization → Clustering

- Service logs are aggregated using “logwatch” everyday
  - Need to make dedicated scripts for each service
  - For DPM, logwatch outputs “Error counts : Error message” format

Error counts	Error message
336780 time(s)	globus-gridftp-server : dmlite DmStatus : Info: [#00.000002] DPM_LFN not found
333902 time(s)	xrootd : dmlite DmStatus : Info: [#00.000002] replica DPM_LFN not found
333900 time(s)	globus-gridftp-server : dmlite DmException : DmException(..):[#00.000002] Error when issuing request to 'http://lcg-se01.icepp.jp:1094/domehead/command/dome_getstatinfo'. Status 404. DavixError: 'HTTP NUMBER : File not found '. Response (NUMBER bytes): 'File not found on rfn: DPM_LFN err: NUMBER what: '[#00.000002] replica DPM_LFN not found'
…	…

  - Meaningless words are replaced with common words
    e.g) 0xabcdef (memory address) → NUMBER
  - The outputs are saved in sqlite3 file for subsequent ML processes

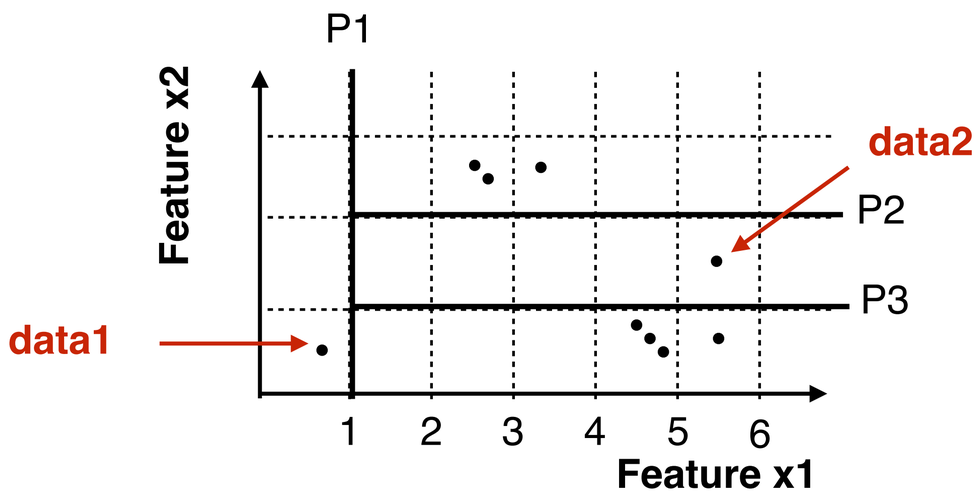
- Texts are converted to vectors using word embedding technique
  - doc2vec algorithm (link) is used in this study
  - Use a neural network that predict a target word from context
    - ✓ You ○○ goodby and I say hello → what is ○○ ?

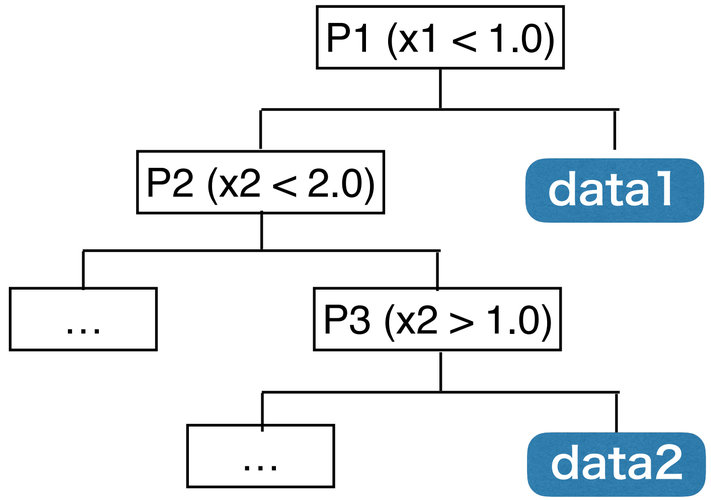


- Weights (W) represents word vectors
- For paragraph, additional matrix is defined for paragraph-id, which represents paragraph vectors

Preprocessing → Vectorization → Clustering

- Clustering n-dimension (feature) vectors in the hidden layer
  - IsolationForest algorithm (link) is used
  - Decision trees are defined with random feature and value
    → Anomaly data tend to result in small number of partitions





1 partition for data1
3 partitions for data2

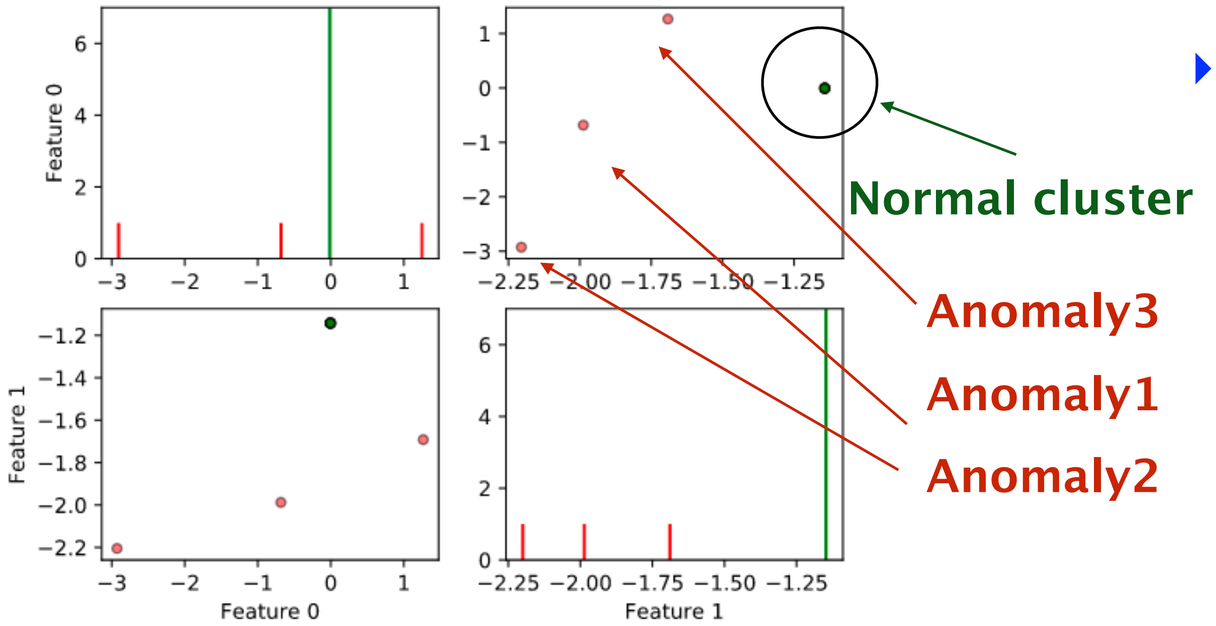
→ data1 is likely to be anomaly

  - Not need to define the number of clusters as input parameter

Simple test using dummy data

- Simple dummy data (sshd log) are defined to check the idea

Label	Text logs	# of samples
Normal	`Users logging in through sshd: root: 2001:2f8:102d:589:2:1:2:1 : 288 times`	7
Anomaly1	`Users logging in through sshd: root: 2001:2f8:102d:589:2:1:2:1 : 300 times`	1
Anomaly2	`Users logging in through sshd: root: 2001:2f8:102d:589:2:1:2:1 : 1000 times`	1
Anomaly3	`Users logging in through sshd: root: 2001:2f8:102d:589:2:1:2:1 : 288 times` `2001:2f8:102d:589:2:1:2:2 : 10 times`	1



- Converted to two-dimension vectors
  - Numbers are converted to other words to show similarity
    - ✓ 25 → digit2to2 bit2to2 digit2to1 bit2to2to5
    - ✓ 26 → digit2to2 bit2to2 digit2to1 bit2to2to5
  - **Anomaly logs are detected as expected using clustering algorithm**

DPM logs

- Use DPM logs from May 29 2019 to Aug 31 2019 at Tokyo Tier2
  - Logs are aggregated everyday using logwatch → 1 day = 1 sample

Date	# of samples	
May 29 - Aug 7	71	Tuning data
Aug 8 - Aug 31	23	Validation data

- Hyper parameters of doc2vec and IsolationForest are tuned using tuning data
  - There were 7 days operational issues in this tuning data period
    - ✓ e.g.) Configuration of quota was wrong, then data transfers failed

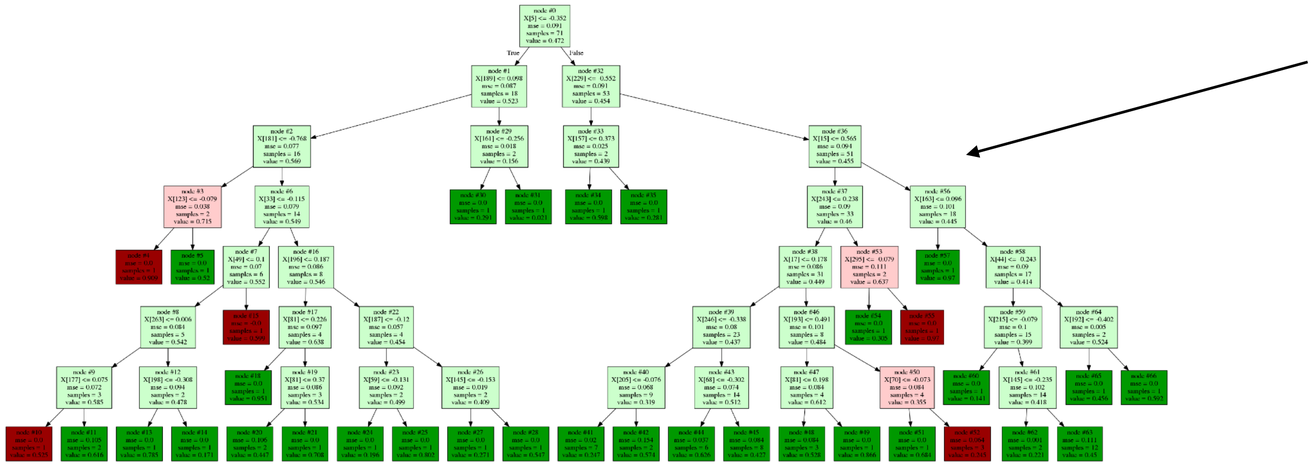
DPM log

```
dmlite DmException : DmException(..):[#00.000028] Error when issuing request to 'http://lcg-
se01.icepp.jp:1094/domehead/command/dome_put'. Status 507. DavixError: 'HTTP NUMBER : Insufficient
Storage '. Response (NUMBER bytes): 'Unable to complete put for DPM_LFN - quotatoken 'ATLASGROUPDISK'
has insufficient free space. minfreespace_bytes: NUMBER
```

  - These 7 days are labeled as anomaly, then hyper parameters are tuned to maximize performances

Hyper parameters

- doc2vec:
  - Vector size (dimensionality of feature vectors): 2,3,4,5,10,30,50,100,200,**300**,400,500
  - Vector window (distance between the current and predicted word): 3,4,5,6,**7**,8,9,10
  - Epochs: 100, **500**, 1000, 2000, 3000
- IsolationForest
  - N estimators (# of base estimators in the ensemble): 5,**10**,30
  - Contamination (amount of anomaly data): 0.10, **0.11**, 0.12, 0.13, 0.14



Decision tree of IsolationForest
Green: normal leaf
Red: anomaly leaf

Anomaly leaf tends to have short path length

Results using tuning/validation data

- Tuning data:

Accuracy of anomaly detection	Accuracy of normal detection
6/7 = 0.86	62/64 = 0.97

→ **Reasonable accuracies are achieved for pre-labeled anomalies**
→ **Will have an anomaly alert ~once a week in this example**

- Validation data:
  - 4 days (Aug 24, 27, 28, 29) are detected as anomaly
  - DPM was upgraded on Aug 27, DPM showed new type of logs after the upgrade
    → **Aug 27, 28, 29 are detected as anomaly as expected**
  - Can not understand clear reason for Aug 24 (false alert)

Summary and consideration

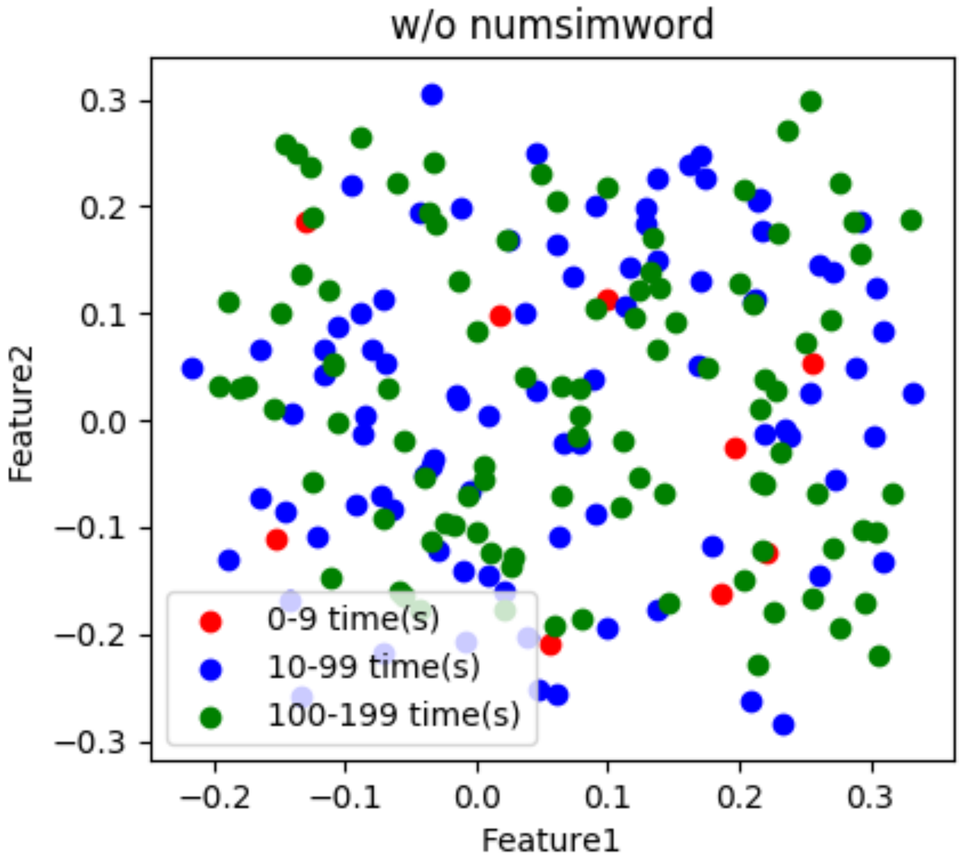
- Anomaly detection using unsupervised Machine Leaning technique for Grid site operation is discussed
  - doc2vec and IsolationForest algorithms are used and this workflow is validated using simple data
  - This workflow is applied to the real DPM logs at Tokyo Tier2:
    - ✓ Reasonable accuracy of anomaly detection is observed, $6/7 = 0.86$ in tuning data
    - ✓ Even if unsupervised Machine Learning is used, data labeling is still required to tune hyper parameters
    - ✓ Difficult to understand reason of false alerts

- Plan: Study a possibility to include information other than text logs, such as CPU usage, memory usage, etc, to detect anomalies

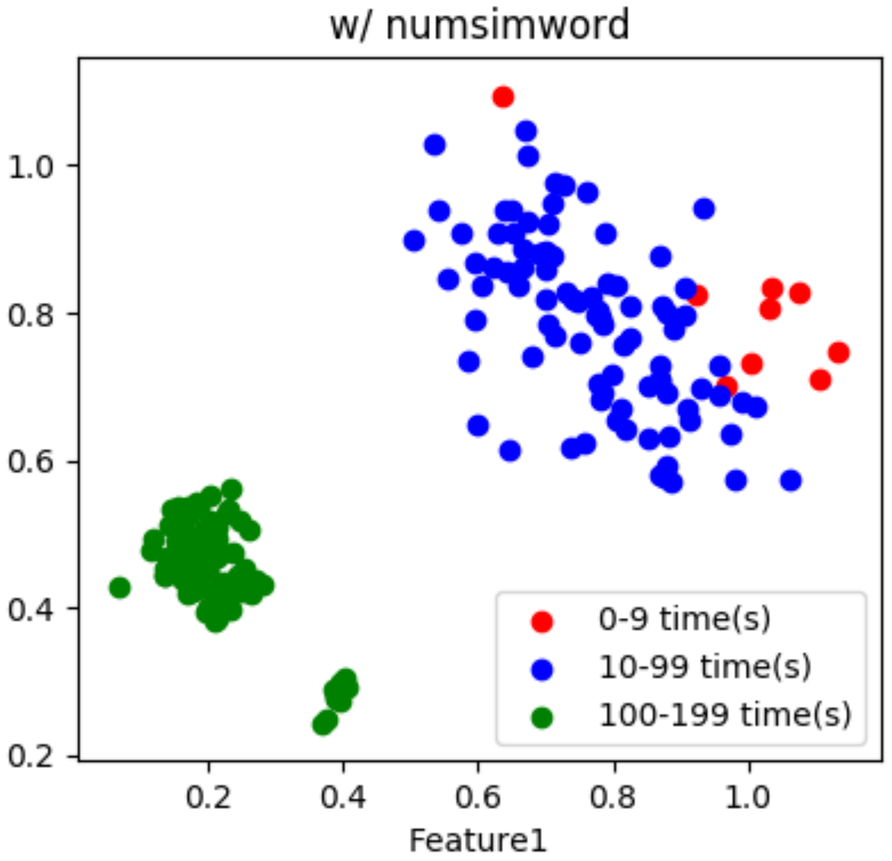
Backup

Number conversion

w/o number conversion



w/ number conversion



Example of DPM logs

```
   384756 time(s) : xrootd :  dmlite DomeMetadataCache::purgeExpired purgeExpired_fileid : Cached empty record (fileid: NUMBER)
    72794 time(s) : globus-gridftp-server :  dmlite DmStatus : Info: [#00.000002] DPM_LFN not found
    72258 time(s) : globus-gridftp-server :  dmlite DmException : DmException(..):[#00.000002] Error when issuing request to 'http://lcg-se01.icepp.jp:1094/domehead/command/dome_getstatinfo'. Status 404. DavixError: 'HTTP NUMBER : File not found '. Response (NUMBER bytes): 'File not
found on rfn: DPM_LFN err: NUMBER what: '[#00.000002] replica DPM_LFN not found'
    29337 time(s) : xrootd :  dmlite DmStatus : Info: [#00.000002] replica DPM_LFN not found
    27281 time(s) : xrootd :  dmlite DmStatus : Info: [#00.000002] file FILE_NAME not found (cached)
    24205 time(s) : xrootd :  dmlite DmStatus : Info: [#00.000002] file FILE_NAME not found
    21888 time(s) : globus-gridftp-server :  dmlite DmException : DmException(..):[#00.000022] Error when issuing request to 'http://lcg-se01.icepp.jp:1094/domehead/command/dome_makedir'. Status 400. DavixError: 'HTTP NUMBER : Server Error '. Response (NUMBER bytes): 'Cannot create
dir DPM_LFN - 22-[#00.000022] Can't create folder RAMDOM_DIR
    16738 time(s) : globus-gridftp-server :  dmlite DmException : DmException(..):[#00.000013] Error when issuing request to 'http://lcg-se01.icepp.jp:1094/domehead/command/dome_get'. Status 500. DavixError: 'HTTP NUMBER : Unexpected server error: NUMBER '. Response (NUMBER bytes):
'Only pending replicas are available.
    12918 time(s) : httpd :  dmlite DmStatus : Info: [#00.000002] DPM_LFN not found
     9234 time(s) : globus-gridftp-server :  dmlite DmException : DmException(..):[#00.000002] Error when issuing request to 'http://lcg-se01.icepp.jp:1094/domehead/command/dome_unlink'. Status 404. DavixError: 'HTTP NUMBER : File not found '. Response (NUMBER bytes): 'Cannot stat
DPM_LFN : 2-[#00.000002] file FILE_NAME not found (cached)
     8954 time(s) : globus-gridftp-server :  dmlite DmException : DmException(..):[#00.000028] Error when issuing request to 'http://lcg-se01.icepp.jp:1094/domehead/command/dome_put'. Status 507. DavixError: 'HTTP NUMBER : Insufficient Storage '. Response (NUMBER bytes): 'Unable to
complete put for DPM_LFN - quotatoken 'ATLASGROUPDISK' has insufficient free space. minfreespace_bytes: NUMBER
     6851 time(s) : globus-gridftp-server :  dmlite DmException : DmException(..):[#00.000002] Error when issuing request to 'http://lcg-se01.icepp.jp:1094/domehead/command/dome_unlink'. Status 404. DavixError: 'HTTP NUMBER : File not found '. Response (NUMBER bytes): 'Cannot stat
DPM_LFN : 2-[#00.000002] file FILE_NAME not found
     5970 time(s) : xrootd :  dmlite setMessage : DmException(..):[#03.001062] Duplicate entry FILE_KEY for key 'file_full_id' at #012[bt]: (NUMBER) /usr/lib64/libdome-4.so : dmlite::Statement::throwException()+0x43 HEXNUMBNER (NUMBER) /usr/lib64/libdome-4.so :
dmlite::Statement::execute()+0x558 HEXNUMBNER (NUMBER) /usr/lib64/libdome-4.so : DomeMySql::create(dmlite::ExtendedStat&)+0x3f2 HEXNUMBNER (NUMBER) /usr/lib64/libdome-4.so : DomeMySql::makedir(dmlite::ExtendedStat const&, std::string, unsigned int, int, int)+0x1ec HEXNUMBNER
     5963 time(s) : xrootd :  dmlite DmStatus : Info: [#00.000017] File RAMDOM_DIR parent: NUMBER already exists - mysql duplicate key. err: 1062-[#03.001062] Duplicate entry FILE_KEY for key 'file_full_id'
     5959 time(s) : xrootd :  dmlite DmStatus : Info: [#00.000022] Can't create folder RAMDOM_DIR
     5958 time(s) : xrootd :  dmlite dome dome_makedir : Cannot create dir DPM_LFN - 22-[#00.000022] Can't create folder RAMDOM_DIR
     4972 time(s) : xrootd :  dmlite DmStatus : Info: [#00.000022] '' is not a valid checksum type.
      485 time(s) : globus-gridftp-server :  dmlite DmException : DmException(..):[#00.000002] Error when issuing request to 'http://lcg-se01.icepp.jp:1094/domehead/command/dome_unlink'. Status 404. DavixError: 'HTTP NUMBER : File not found '. Response (NUMBER bytes): 'Cannot get
parent of DPM_LFN : 2-[#00.000002] Entry RAMDOM_DIR not found under DPM_LFN
      222 time(s) : globus-gridftp-server :  dmlite DmException : DmException(..):[#00.000022] DavixError (NUMBER) Failure HTTP NUMBER : File not found after NUMBER attempts at #012[bt]: (NUMBER) /usr/lib64/dmlite/plugin_domeadapter.so :
dmlite::DomeTunnelHandler::checkErr(Davix::DavixError**)+0xea HEXNUMBNER (NUMBER) /usr/lib64/dmlite/plugin_domeadapter.so : dmlite::DomeTunnelHandler::DomeTunnelHandler(dmlite::DavixCtxPool&, std::string const&, int, unsigned int)+0x135 HEXNUMBNER (NUMBER) /usr/lib64/dmlite/
plugin_domeadapter.so : dmlite::DomeIODriver::createIOHandler(std::string const&, int, dmlite::Extensible const&, unsigned int)+0x31b HEXNUMBNER (NUMBER) /lib64/libdmlite.so.0 : dmlite_fopen+0x249 HEXNUMBNER
      178 time(s) : xrootd :  dmlite dome fillSecurityContext : Cannot add unknown group ''
      171 time(s) : globus-gridftp-server :  dmlite DmException : DmException(..):[#00.000002] Error when issuing request to 'http://lcg-se01.icepp.jp:1094/domehead/command/dome_makedir'. Status 404. DavixError: 'HTTP NUMBER : File not found '. Response (NUMBER bytes): 'Can't find
parent path of DPM_LFN
       57 time(s) : xrootd :  dmlite DmStatus : Info: [#00.000002] DPM_LFN not found
ed by DPM_LFN
       23 time(s) : globus-gridftp-server :  dmlite DmException : DmException(..):[#00.000013] Error when issuing request to 'http://lcg-se01.icepp.jp:1094/domehead/command/dome_put'. Status 403. DavixError: 'HTTP NUMBER : Permission refused '. No response to show. at #012[bt]:
(NUMBER) /usr/lib64/dmlite/plugin_domeadapter.so : dmlite::DomeAdapterPoolManager::whereToWrite(std::string const&)+0x123f HEXNUMBNER (NUMBER) /lib64/libdmlite.so.0 : dmlite_put+0x9c HEXNUMBNER (NUMBER) /usr/lib64/libglobus_gridftp_server_dmlite.so : dmlite_gfs_check_node+0x101
HEXNUMBNER (NUMBER) /usr/lib64/libglobus_gridftp_server_dmlite.so : +0x51dd HEXNUMBNER
       19 time(s) : globus-gridftp-server :  dmlite DmException : DmException(..):[#00.000022] Error when issuing request to 'http://lcg-se01.icepp.jp:1094/domehead/command/dome_chksum'. Status 500. DavixError: 'HTTP NUMBER : Unexpected server error: NUMBER '. Response (NUMBER bytes):
'Found a previous finished checksum calculation that likely failed. namekey: DPM_LFN checksum calculations in queue right now: NUMBER
       19 time(s) : globus-gridftp-server :  dmlite DmException : DmException(..):[#00.000013] Error when issuing request to 'http://lcg-se01.icepp.jp:1094/domehead/command/dome_makedir'. Status 403. DavixError: 'HTTP NUMBER : Permission refused '. No response to show. at #012[bt]:
(NUMBER) /usr/lib64/dmlite/plugin_domeadapter.so : dmlite::DomeAdapterHeadCatalog::makeDir(std::string const&, unsigned int)+0x323 HEXNUMBNER (NUMBER) /lib64/libdmlite.so.0 : dmlite_mkdir+0x8b HEXNUMBNER (NUMBER) /usr/lib64/libglobus_gridftp_server_dmlite.so : +0x4176 HEXNUMBNER
(NUMBER) /usr/lib64/libglobus_gridftp_server_dmlite.so : +0x6ac4 HEXNUMBNER
       10 time(s) : globus-gridftp-server :  dmlite DmException : DmException(..):[#00.000002] Error when issuing request to 'http://lcg-se01.icepp.jp:1094/domehead/command/dome_put'. Status 404. DavixError: 'HTTP NUMBER : File not found '. Response (NUMBER bytes): 'Cannot stat the
parent of lfn: DPM_LFN
        4 time(s) : xrootd :  dmlite dome calculateChecksum : Found a previous finished checksum calculation that likely failed. namekey: DPM_LFN checksum calculations in queue right now: NUMBER
        4 time(s) : globus-gridftp-server :  dmlite DmException : DmException(..):[#00.000002] Error when issuing request to 'http://lcg-se01.icepp.jp:1094/domehead/command/dome_makedir'. Status 404. DavixError: 'HTTP NUMBER : File not found '. Response (NUMBER bytes): 'Can't find
parent path of '/dataXX/ops/20XX-XX-XX'
        4 time(s) : globus-gridftp-server :  dmlite DmException : DmException(..):[#00.000002] Error when issuing request to 'http://lcg-se01.icepp.jp:1094/domehead/command/dome_makedir'. Status 404. DavixError: 'HTTP NUMBER : File not found '. Response (NUMBER bytes): 'Can't find
parent path of '/dataXX/ops'
        3 time(s) : httpd :  dmlite setMessage : DmException(..):[#00.000013] Missing token on pfn: /.well-known/oauth-authorization-server at #012[bt]: (NUMBER) /usr/lib64/dmlite/plugin_domeadapter.so : dmlite::DomeIODriver::createIOHandler(std::string const&, int, dmlite::Extensible
const&, unsigned int)+0xae4 HEXNUMBNER (NUMBER) /lib64/libdmlite.so.0 : dmlite_fopen+0x249 HEXNUMBNER (NUMBER) /usr/lib64/httpd/modules/mod_lcgdm_disk.so : +0x70d8 HEXNUMBNER (NUMBER) /usr/lib64/httpd/modules/mod_lcgdm_dav.so : +0x455f HEXNUMBNER
        3 time(s) : httpd :  dmlite setMessage : DmException(..):[#00.000013] Missing token on pfn: /favicon.ico at #012[bt]: (NUMBER) /usr/lib64/dmlite/plugin_domeadapter.so : dmlite::DomeIODriver::createIOHandler(std::string const&, int, dmlite::Extensible const&, unsigned int)
+0xae4 HEXNUMBNER (NUMBER) /lib64/libdmlite.so.0 : dmlite_fopen+0x249 HEXNUMBNER (NUMBER) /usr/lib64/httpd/modules/mod_lcgdm_disk.so : +0x70d8 HEXNUMBNER (NUMBER) /usr/lib64/httpd/modules/mod_lcgdm_dav.so : +0x455f HEXNUMBNER
        1 time(s) : globus-gridftp-server :  dmlite DmException : DmException(..):[#00.000013] Error when issuing request to 'http://lcg-se01.icepp.jp:1094/domehead/command/dome_unlink'. Status 0. DavixError: '(Neon): Could not read status line: connection was closed by server'. No
response to show. at #012[bt]: (NUMBER) /usr/lib64/dmlite/plugin_domeadapter.so : dmlite::DomeAdapterHeadCatalog::unlink(std::string const&)+0x25d HEXNUMBNER (NUMBER) /lib64/libdmlite.so.0 : dmlite_unlink+0x83 HEXNUMBNER (NUMBER) /usr/lib64/libglobus_gridftp_server_dmlite.so : +0x41ab
HEXNUMBNER (NUMBER) /usr/lib64/libglobus_gridftp_server_dmlite.so : +0x6ac4 HEXNUMBNER
        1 time(s) : globus-gridftp-server :  dmlite DmException : DmException(..):[#00.000022] Error when issuing request to 'http://lcg-se01.icepp.jp:1094/domehead/command/dome_getidmap'. Status 0. DavixError: '(Neon): Could not read status line: connection was closed by server'. No
response to show. at #012[bt]: (NUMBER) /usr/lib64/dmlite/plugin_domeadapter.so : dmlite::DomeAdapterAuthn::uncachedGetIdMap(std::string const&, std::vector<std::string, std::allocator<std::string> > const&, dmlite::UserInfo*, std::vector<dmlite::GroupInfo,
std::allocator<dmlite::GroupInfo> >*)+0xf26 HEXNUMBNER (NUMBER) /usr/lib64/dmlite/plugin_domeadapter.so : dmlite::DomeAdapterAuthn::getIdMap(std::string const&, std::vector<std::string, std::allocator<std::string> > const&, dmlite::UserInfo*, std::vector<dmlite::GroupInfo,
std::allocator<dmlite::GroupInfo> >*)+0x314 HEXNUMBNER (NUMBER) /usr/lib64/dmlite/plugin_domeadapter.so : dmlite::DomeAdapterAuthn::createSecurityContext(dmlite::SecurityCredentials const&)+0xa9 HEXNUMBNER (NUMBER) /lib64/libdmlite.so.0 :
dmlite::StackInstance::setSecurityCredentials(dmlite::SecurityCredentials const&)+0x2f6 HEXNUMBNER
        1 time(s) : xrootd :  dmlite DmStatus : Info: [#00.000020] '' is not a directory, and is referenced by DPM_LFN
```