emlix embedded linux systems

Elektrobit

Tech paper

elos – Flexible event logging and management with normalized output-format for Linux

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Summary
of Tech paper contents

Event-driven architectures (EDA[1]) assume that everything can be hooked to events and only when the event occurs actions are started.

There are numerous benefits of EDA:

- Limited computer resources are shared over an enormous number of events and receivers that only work if needed and do not waste compute resources for polling
- Already existing architectures of FOSS components assume an EDA
- Foundation of a micro-service architecture is set-up

In a Linux environment, such architectures find a natural habitat and many FOSS-components are available to support.

The Linux kernel for example, has many interfaces that can be used to be notified of important events. The same is true for startup systems and network attached frameworks such as MQTT.

When looking at these different systems, it becomes clear that each has its own understanding of events, their arguments and the interface used to retrieve and send out events.

elos supports design of EDAs by handling events of any kind with structured and configurable solutions.

Types of generic operating-system-near events:

- Simple events: startup/shutdown/config-change
- Seldom events: update-processes, reset, factory-reset
- Hardware events: high temperature, error of hardware
- Critical events: hardware failure occurred, failed selftest
- Debug events: out of memory, cpu overload
- Security events: failed log-ins, replacement of credentials

All above events have a very heterogeneous format and way of handling.

elos helps in overcoming this, using a canonical event format.

We begin with an example use case:

Requirement: The client-application shall be started after the server-application has finished its initialization.

Questions to be answered in detailed design:

- Which event is the right start-signal to start the client?
  - when the port is open?
  - when the process is there?
  - when a specific log line is written?
  - when the process sends a signal?

All these events are valid to be used as a trigger event for the client-start, but they are challenging to implement and maintain,
- What happens if the port changes?
- What happens if the log isn’t printed any longer?
- What happens if the receiver needs to be extended?

All of the above questions can be answered by writing a script that checks for *xyz* every 5s and then types *zyx*. However, that is neither efficient nor quick, and far from maintainable.

elos approaches this by splitting up and separating event detection, event structure, event distribution, event filtering, event storage and handling.

1. elos – The event and signal funnel

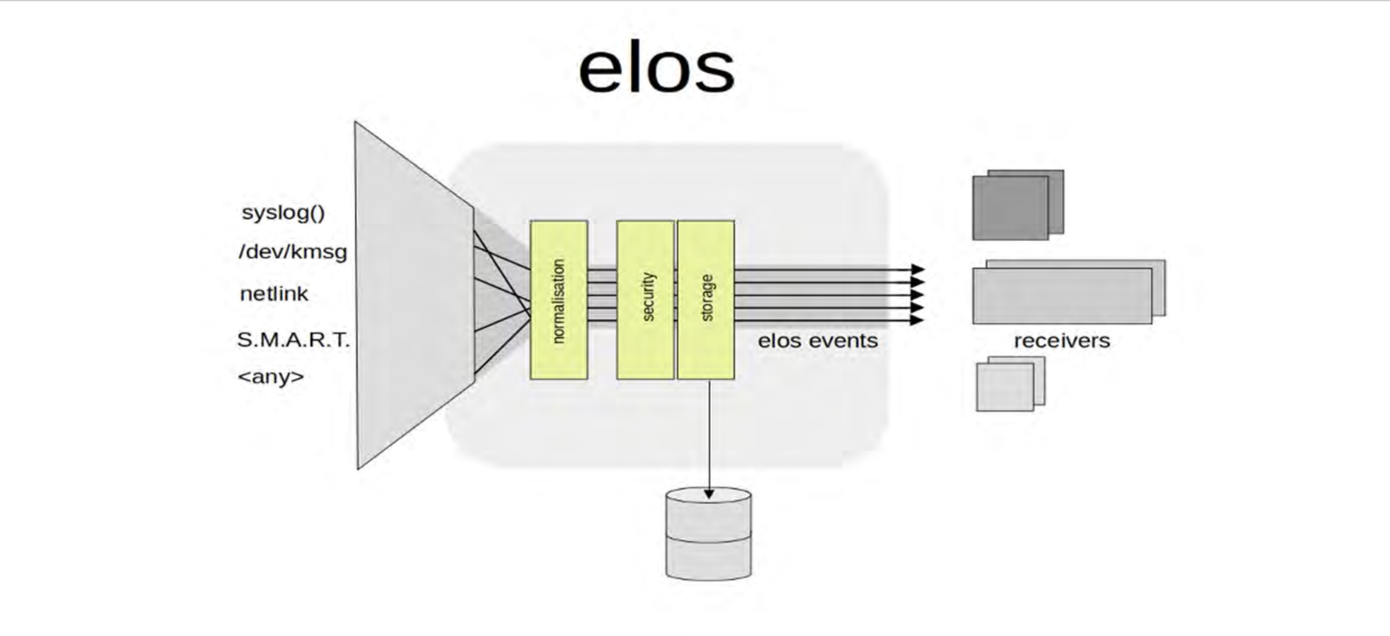


Figure 1: elos: a funnel for events from multiple heterogeneous sources

Design

elos provides a clean separation in the flow of events:

- event producer
- event distribution and filtering
- event receiving and handling
- event logging to storage

Events from many different sources are collected by elos or can be provided to elos for verification. elos takes all of these events and funnels them to receivers that are interested in that specific event.

elos takes any line printed to syslog or kernel log as a potential event and is even able to react on ‘silent’ events that only cause a line in a log to be printed with no further activities.

In the given server client example, the producer side needs to be modified in case the port number changes. The event itself stays unmodified and no event receiver will experience any change.

Basic architecture of elos

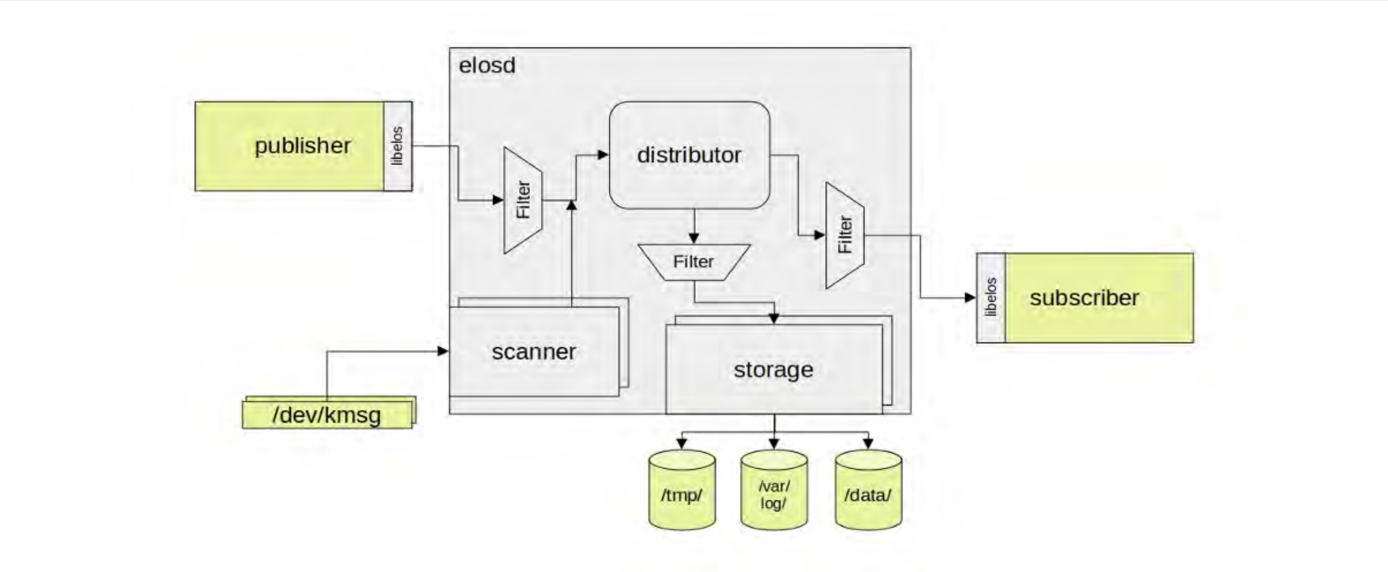


Figure 2: Basic inner architecture of elos and its interfaces

elos accepts events from any process using the C API provided by the libelos library to send events via Inter Process Communication (IPC) channels. In case libelos cannot be used, the protocol can also be implemented directly.

The events undergo a first filter-stage to ensure the sender is only sending events it is allowed to send with a defined and configurable maximum rate.

Alternatively, elos can itself “scan” for events in the system. This is accomplished by a module loaded to the elos process. Such scanners are used to scan the system log and kernel log for events.
The inner event distribution engine of elos forwards the events to the potential subscribers and the logging subsystem.

Depending on the filter configuration, the event is then delivered. The subscriber receives the event and can further analyze, process and react to it as needed.

The same filtering technique is used to select the storage of each event. Depending on the filter-setting, the event is stored in the respective storage system either permanently or until the next reboot. The maximum retention time and log size is configurable.

Event format

To handle events efficiently, a unique format is needed. elos defines a canonical format. The canonical format contains strongly and weakly typed fields. Strongly typed fields have a strictly defined format (usually integer) with a fixed elos-wide mapping of numbers and semantics (e.g. a message code of 4004 always means that something cannot be found, it is obviously inspired by HTTP[2]). Weakly typed fields can be freely filled by the sender with any kind of information (usually JSON[3] encoded data structures). This mixture allows flexibility and efficient generic filtering at the same time.

Canonical format

```
date : timestamp in nano seconds resolution
source.appName : string
source.fileName : string
source.pid : int
severity : int
hardwareid : string
message code : int (inspired by http)
classification : flags
payload: (text, number, structs)
```

The *payload* field has no specific type and can be used freely. The *source* field contains - if applicable - the name and identities of the emitting entity. If the kernel has sent the event, the pid will be set to 0.

All other fields are strongly typed and need to be filled out respectively.

The message code field has a predefined set of code inspired by HTTP status codes but mapped to a wider range, hence 4004 means that a file was not found.

Example events

Assuming an embedded in-vehicle environment, where typical Linux events shall be processed:

Program internal error

In the case of a segmentation fault (SIGSEGV) from a process, a mail or MQTT message is sent to some cloud service. The event might look like this:

```
date : 123456
source.appName : myApp
source.fileName : /home/user/myApp
source.pid : 1234
severity : 0x2 (=error)
hardwareid : myMachine
message code : 5002
classification : 0x20
payload:
{
  "function":"main",
  "address": "0x12424f2",
  "..."
}
```

The receiver of the event decodes the payload and might collect further data from the ECU, the comprehensive data is then sent to e.g. a cloud-instance.

Use ssh as soon as possible

It is required to start sshd as soon as a network is attached.

The event might look like this and was derived from networking kernel interfaces:

```
date : 123456
source.appName : kernel
source.fileName : -
source.pid : 0
severity : 0x04 (=info)
hardwareid : myMachine
message code : 7003
classification : 0x02
payload:
{
  "interface": "eth0",
  "action": "plugged"
}
```

Open debugging interfaces if external switch was pressed

Start the debug service as soon as a general purpose input (GPIO) is switched. The event might look like this:

```
date : 123456
source.appName : kernel
source.fileName : -
source.pid : 0
severity : 0x04 (=info)
hardwareid : myMachine
message code : 7005
classification : 0x80
payload:
{
  "interface": "gpio23",
  "action": "raise"
}
```

Report a security incident

Suspicious network pakets did cross the TCP/IP stack and the packet filter detected them. The resulting logs were converted by a scanner of elos to an event looking like this:

```
date : 123456
source.appName : kernel
source.fileName : -
source.pid : 0
severity : 0x03 (=warning)
hardwareid : myMachine
message code : 4002
classification : 0x02
payload:
{
  “interface”: “eth0”,
  “action”: “package dropped”,
  {
  ... further info on the package
  }
}
```

A possible reaction would be to stop all network activities and shut down the ECU as a cybersecurity attack might be ongoing. This way elos can be used to design a cyber security response as required in UN-ECE R155 5.1.1 (d)[4].

But it could also be fine to just store the event in the logs of elos for later cybersecurity audits. In the latter case no receiver needs to be implemented. This resulting log is of use for implementation of UN-ECE R155 5.1.1 (e) “analysis of attempts of cyberattacks”.

2. Event collection – input side

Input from scanners

On the input side elos supports loading of shared objects into the main process. These modules scan the system for events and feed them into the internal event queue of elos. Thus, these modules are called scanners.

Depending on the nature of the events, scanners poll for an event regularly using their own threads or sleep until an event is reported.

Elos handles the syslog and the kernel log with dedicated scanners. They parse the metadata of each log line for source, severity, etc. The original line can at any time be retrieved from the payload.

The syslog scanner behaves like an ordinary POSIX syslogger: It receives all log lines sent using the `syslog` () function. Each line is converted by the scanner to an event in canonical format.
The kernel log scanner looks for logs from the kernel by reading `/dev/kmsg`. Each log line from the kernel is converted to an event and processed by elos.

The network scanner makes use of “netlink”[5] and “netdevice”[6] to detect events concerning network activities like plugging of connections, etc. Whenever a change was detected, a generic event in canonical format is pushed to the elos queue to allow follow-up actions.

Input via API / Socket

Additionally to the scanners, external processes can deliver events for processing and forwarding to elos, either via local IP or Unix-Domain-Socket.

The library libelos allows easy creation of the needed protocol structures. Any other environment not using the library needs to implement the simple and straightforward protocol. This way applications written in any arbitrary programming language can make use of the logging and event handling features. It is left to system architects to make use of this interface for highly specific events of any kind, for example, in the application software layers.

Example:

A small C++-based application polls the temperature sensor every 5 seconds. If it is higher than a certain limit, an event is pushed to elos.

That event is filtered and forwarded to all applications doing heavy calculations (e.g. doing some Artificial Intelligence). The event causes these applications to slow down or even to stop their calculations, which is expected to stop further temperature increases.

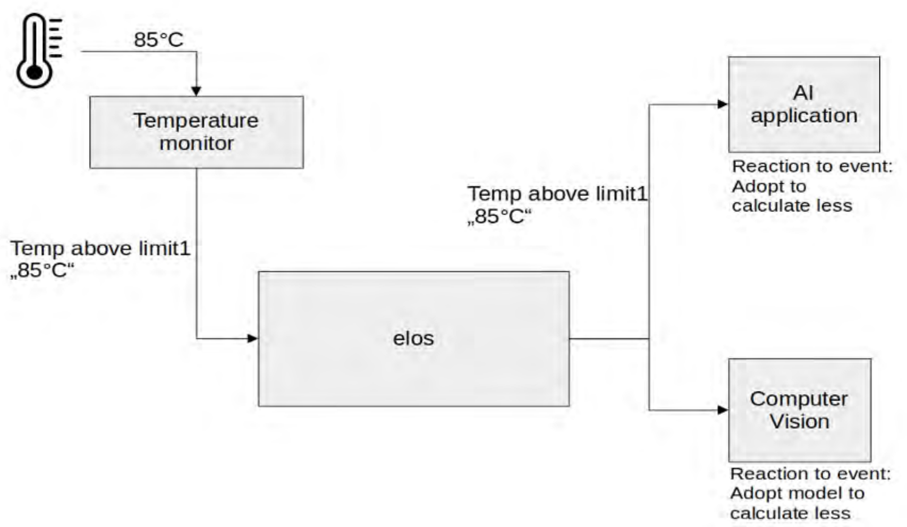


Figure 3: Example architecture to handle over temperature situations

Example:

Another application using the SMART[7] tools to check the status of the flash-based storage reports events via elos.

These events are received and processed by a predictive maintenance application. This allows a replacement of the storage before it is running out of spare sectors or it just reduces the write activities until replacement.

During development or testing of a vehicle, these kinds of events can help to forecast the degree of wear of the flash and from that the expected end of life of the storage can be deduced and finally optimized.

Security aspects

The receivers of events from elos usually take actions depending on the type and content of the event. For example, a receiver responsible for a clean shutdown will shutdown that ECU in case a battery-low event was sent. If any process is able to send a fake low-power event via elos, an unintended shutdown will be initialized.

The countermeasure to this scenario is provided by the elos input filtering. Only previleged processes are allowed to send in such critical events. The processes and events are defined the elos config using rpn-filters.

The processes allowed to send such events are defined by their ELF-file. In the above example a process running the executable /usr/bin/system-manager might be allowed to send such events. If the process has a different executable the event is refused.

The extensions of elos to do the event authorization via powerful cryptographic algorithms is planned.

Subscribe to 'your' events

Via the elos IPC interface any process can register with elos for event retrieval, e.g. by using the libelos.

After registration, a filter needs to be defined to start receiving events. Any event that matches the filter is then delivered. It is now up to the receiving process to further analyze the event or to start an activity right away.

Example:

A plugged-event or link up event from the network-subsystem can be enough of information to start connecting to a server. The analysis of the details and the payload of the event can be omitted, making the receiver less complex.

On the other hand, and depending on the nature of the event, the receiver might need to analyze the event in detail to derive the proper reaction. Analysis of the payload might become a more complex task as JSON or similar structures need to be parsed.

Depending on this analysis, the process may react to the event in an appropriate way, ignore it or even send another event via elos.

The elos filters operate on the canonical format of the events. They are formulated in reverse polish notation (RPN)[8]. Any field of the canonical format including the payload can be used for filtering. Filters are allowed to use logical operators like 'and', 'or' or 'not', etc, and combinations of them.

Example:

Filter:
In RPN: "`.event.messageCode 2007 EQ .event.source.appName 'sshd' EQ AND`"
In infix-notation: "`.event.messageCode=2007 && event.source.appName = 'sshd' `"

This filter maps to the 2007 Code (meaning socket open) from sshd. Hence the receiver will be informed when the ssh-server is ready to be used.

Hint: The details for detecting this state are left to the input side of elos, making event detection and handling independent.

Example:

Filter: "`.event.messageCode 5005 EQ`"
The message code 5005 tells us that a process has crashed and core-dumped. The resulting action could be to collect forensic data and send them to the cloud in order to allow further analysis of the issue. Additionally the remaining running software could use this event to change into a safe-mode to prevent follow-up issues.

Example:

In this design example some battery handling is assumed. A battery monitoring process is regularly checking the conditions of all batteries and sends events in case some relevant status has changed. The main batteries communicate via the CAN-Bus but backup batteries use the Linux default "power_supply" subsystem.

The battery monitoring process sends the following events when appropriate:

```
date : 123456
source.appName : battery_mon
source.fileName : -
source.pid : 4321
severity : 0x04 (=info)
hardwareid : myMachine
message code : 7007
classification : 0x02
payload:
{
  "remaining_time": "1h",
}
```

Any receiver of this event can now react in an individual way to cope with the fact that 1h of run time is left. Reactions could be to warn the driver or to switch off heating.

Another event from the battery monitoring process could be:

```
date : 123456
source.appName : battery_mon
source.fileName : -
source.pid : 4321
severity : 0x03 (=warning)
hardwareid : myMachine
message code : 7008
classification : 0x02
payload:
{
  "remaining_time": "30s",
}
```

With this information, each process should stop energy hungry calculation immediately. To save power needed for storing data to flash, a shutdown has to be expected shortly. A more fine-grained design of events around battery monitoring should be created for an actual real-world application, but that is out of the scope of this paper.

Example: Software updates are installing

A software update tooling (e.g. over-the-air updates) can make use of elos by communicating the start and end of an update process to prevent unwanted activities during replacement of software, or to inform the user interface about the progress of the update.

Example: The flash (SSD/eMMC) is detecting issues

Events via elos can be used to implement predictive maintenance. An elos-scanner or any other observing process could generate events depending on the status of the flash-storage. If the number of total-written bytes exceeds a certain amount, or if the count of spare blocks goes below a defined limit, an event is sent out. The reaction to that event might be to request a hardware replacement and a limitation of the writing activities to a minimum. The definitions of limits and resulting actions can be freely designed by the architects of the ECU Software.

Example: starting applications and containers depending on events

With integration of an init-system that allows start, stop and control of running processes and containers, elos enables a system design that starts and stops applications and containers depending on the current use-case of the vehicle.
If a software component detects highway-driving, some containers with specific functions for highway driving are started and the container for parking-service is shutdown.

Example: Get a notification on low free memory (RAM or storage)

The RPN-Filters can even filter with the payload if it is formulated as JSON. Hence a possible system design could be based on regular broadcasting of storage status events, e.g. every 5 minutes. These events carry the actual free space in bytes in the payload. The filters just forward the event in case the byte-count goes below e.g. 100MB and that in turn causes a deletion of data increasing the available space again. Within this design the decision for the trigger limit (here 100MB) was pushed to the receiving side. This shows the amount of flexibility the system designers have when using elos and its infrastructures.

3. Event logging and storage backends

Events passing through elos and influencing all other system parts can have a high impact on the functionality of the ECU, hence these events need to be logged and stored for later reference. But elos events that just occur without software that reacts to them can also play an important role when it comes to analysis of incidents. To allow this analysis and further audits, elos stores events for later reference.

Logging is a critical activity with an impact on the lifetime of the flash storage. If all log information is stored, the available capacity of the flash will not last for a device’s lifetime. The first solution approach to this would be to delete old logs in a circular buffer manner. But that might not be the best solution, as the total number of write cycles of the flash device is still in danger of being exceeded. This would result in dramatically failing storage devices after longer periods of use.

To solve this, elos has a filter-based multi-level approach of logging events in different storage-classes. Each storage-class has a place “where to store”, a filter “what to store”, and further parameters. The filters make use of the generic elos filtering approach. If an event matches to the filter of a storage class, the event is logged using the defined technology to the place defined.

Example:

Events with a high severity might be logged to a SQL-database residing on the eMMC flash. Events stored here are deleted after one year.

Events with a higher severity are logged to a very reliable storage in NOR-Flash using json to allow easy analysis. These types of events are never deleted. Power-Fail-safety needs special care on this device.

Events with severity “debug” are logged in a NoSQL-database to a RAM device to allow debugging. As long as no reboot occurs the data is available.

Events with very low severity are just discarded.

Depending on the design of the storage technology, event logging with integrity protection is possible to allow security audits with a high reliability.

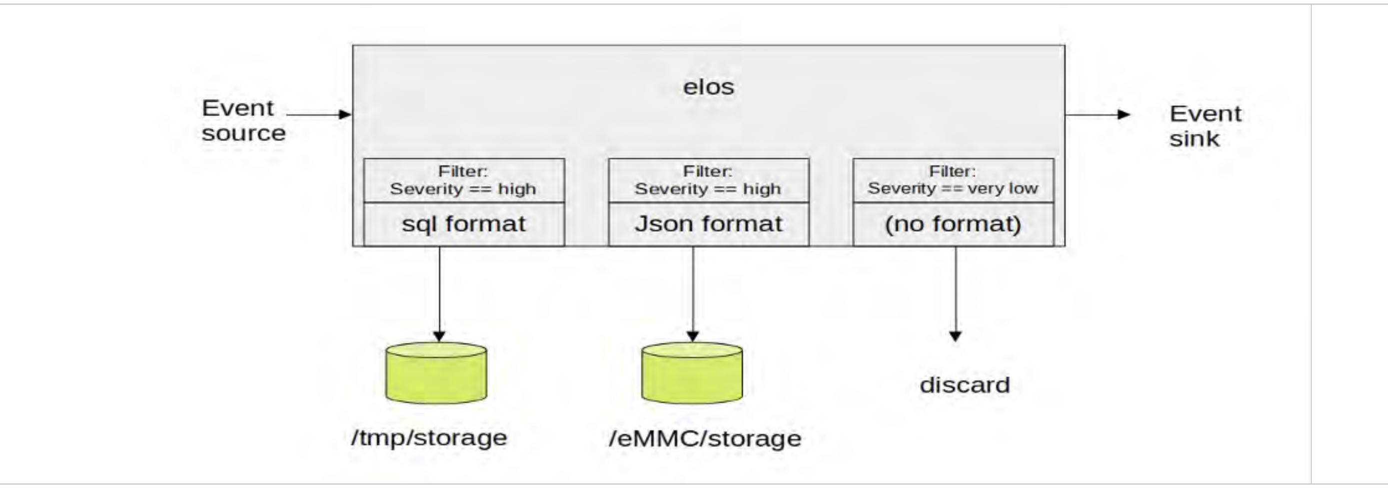


Figure 4: Logging subsystem of elos: Flexible use of different storage

4. Security of the config

The configuration details of elos are crucial for its function and hence for the overall ECU. This leads to the need to secure the configuration files by checking their integrity and verifying their authenticity. The easiest way to do this is by storing the configuration immutably in a dm-verity-secured read-only partition. However that might be impossible as dynamic (re-)configuration is part of many system architectures.

To address these requirements, elos supports fine-grained configuration parameter verification where critical parameters are verified by checking signatures. Only if this check is passed the parameter is accepted, otherwise the default is used.

Non-critical parameters can be set freely in the configuration file.

Example:

The elos configuration for storage of events is secured with a signature of the integration party. No one is able to modify the storage place of events unless authorized. But the internal logging level of elos is left open to allow different selections here.

5. Test suite testing elos

Integration tests

elos contains a test suite that verifies correct function when installed on a Linux-based operating system. The test suite verifies that all components are installed and behave as defined.

Unit tests

elos has a unit test suite that picks each function out of its scope and tests just the bare features of that particular function. Any function that is called by the function under test (FUT) can be mocked to enable stable testing of the function or to inject errors.

6. Documentation

elos comes with a full set of internal and external API documentation along with a user-friendly manual showing the ways to use and configure elos.

7. Conclusion

elos is a light-weight event processing framework for event driven architectures in a Linux environment. It separates the event detection, filtering, processing, storage, and handling and therefore simplifies the design of application software and reduces the maintenance complexity.

elos and its default scanners enable you to hook an event receiver to any line of logging printed to the default logging channels of Linux. This eases the creation of a first working system design that is based on elos.

The details for detecting event are left to the input side of elos, making event filtering and handling independent from the technologies, interfaces and structures of underlying Linux subsystems.

8. Future extensions

Future extensions of elos is aiming to cover aspects of static data. elos is a good candidate to host information that is of system wide interest but without the character of an event, e.g. an hour-counter that just count the time the ECU is actively running, or the number of reboots the ECU has experienced.

9. How to get elos

- elos is part of Elektrobit's open-source software solutions called EB corbos Linux – built on Ubuntu. Visit https://www.elektrobit.com/products/ecu/eb-corbos/Linux/ to learn more.
- elos is an open-source community project. See: https://github.com/Elektrobit/elos
- Contact us for questions: sales@elektrobit.com or elos@emlix.com

10. References

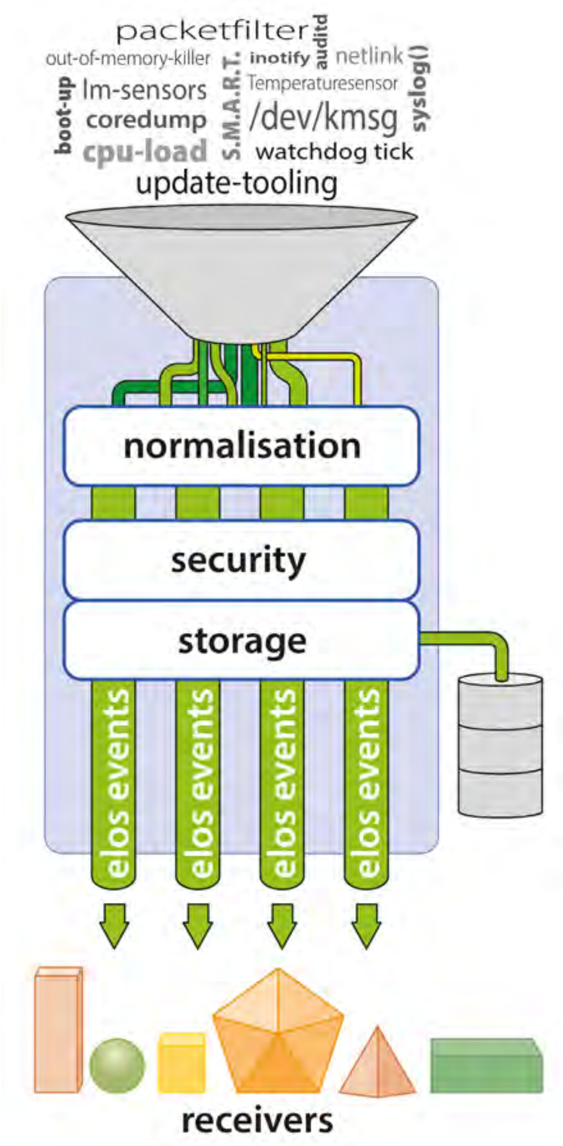
[1] See https://medium.com/swlh/the-engineers-guide-to-event-driven-architectures-benefits-and-challenges-3e96ded8568b
[2] See RFC 7231 „Hypertext Transfer Protocol (HTTP/1.1): Semantics and Content“
[3] See IEC 21778 „The JSON data interchange syntax“
[4] UN-ECE UN Regulation No. 155; Jan 22nd 2021
[5] Linux Manpage netlink(7)
[6] Linux Manpage netdevice(7)
[7] SMART was originally defined in ATA-Standard ACS-2. The features were continued similarly as industry standard in SCSI and even Flash-based storage like NVMe based ones.
[8] Also known as post fix notation. The operator follows the operands.

11. About emlix

emlix offers industrial-grade Linux for the digitalization and secure networking of devices, machines, and plant throughout the entire product life cycle.

For more than 20 years, emlix has been transferring system knowledge, innovations from the open-source world and market knowledge into the products of our more than 350 customers in automotive, energy industry, automation technology, medical technology, safety technology, and others.

As a provider of professional open-source software, we ensure process security and transparency. The tools and development standards we use are designed for industrial requirements and certifications. We offer long-term maintenance contracts for our solutions and thus assume responsibility for the product life cycle and the investments of our customers.



About the authors

Thomas Brinker
emlix GmbH

Thomas Brinker is a Senior Systems Engineer and Project Manager at emlix GmbH. He is an architect for secured embedded Linux systems in the automotive, medical, industrial, and consumer device fields, performing requirements engineering and design throughout the entire product life cycle.

Wolfgang Gehrhardt
emlix GmbH

Wolfgang Gehrhardt is a Senior Systems Engineer at emlix GmbH. He is an architect for secured embedded Linux systems in the automotive, industrial and consumer device fields, performing requirements engineering and design throughout the entire product life cycle.

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For more information, visit us at **elektrobit.com**

Elektrobit Automotive GmbH
Am Wolfsmantel 46
91058 Erlangen, Germany

Phone: +49 9131 7701 0
Fax: +49 9131 7701 6333

sales.automotive@elektrobit.com

www.elektrobit.com