Anomaly detection and trend analysis of critical system states based on Nagios payload

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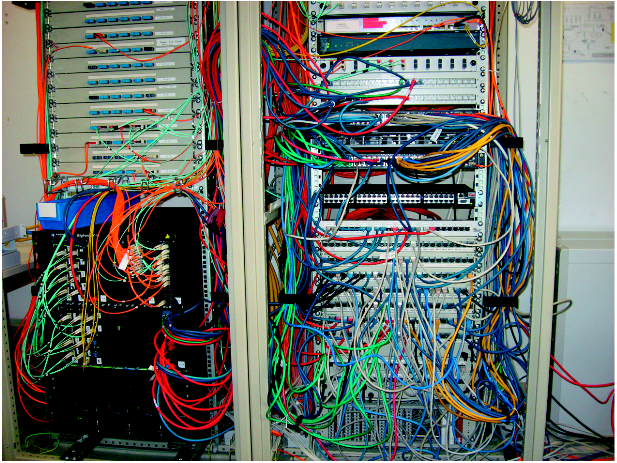
Motivation



- **Worst-Case:** User detects failure within system and reports to IT-Hotline (*frustration on both sides*)

- **Best-Case:** Failure is detected and fixed before user notices anything (*frustration on only one side*)

We face the situation ...

- Nagios can only detect failures via static thresholds[1]
- Is perfect for requesting boolean values (e.g. host is up or not)
- But not so much in combination with numerical data from certain processes ...
- ... process behaviour changes over the time, our static thresholds do not
- ... what if behaviour is anomalous within thresholds?
  - Network traffic,
  - # Mail users,
  - Temperature sensors, ...

[1] OK, WARNING, CRITICAL, UNKNOWN

We face the situation ...

- Can we predict the future?[2]
- Nagios has no possibility for payload extrapolation (trend)
- Possible Use Cases
  - Software licences (e.g. Matlab),
  - Network: volume-based restrictions,
  - HD capacity,
  - Stock quotes ;)

[2] ... rhetorical question

1. Data collection
   - Sniffing bytes over the net ... netsniff-ng
   - Integration into Nagios
2. Data analysis
   - Assumptions about our data ...
   - Anomaly detection techniques
     - Holt-Winters-Forecasting (and some improvements)
     - Clusteranalysis approach
     - Interface to NagiosGrapher
   - Trend analysis
     - Levenberg-Marquardt
     - REA-Framework
3. Links & Q+A

Data collection

Data collection

- For our analysis we need some numerical data ...
- ... as an example, we fetch network packets and generate statistics
- Let's have a short look ...

Sniffing bytes over the net ...
netsniff-ng

tcpdump, libpcap

- Lets evaluate what could be used ...
- `tcpdump` is a userspace network sniffer based on libpcap
- `libpcap`: libpcap is a system-independent interface for user-level packet capture. libpcap provides a portable framework for low-level network monitoring. Applications include network statistics collection, security monitoring, network debugging, etc.[3]

[3] http://sourceforge.net/projects/libpcap/

tcpdump, libpcap

- `libpcap` programming isn't hard, so here we go ... writing a sniffer for Nagios based on `libpcap`
- Sounds great, doesn't it?

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tcpdump, libpcap

- `tcpdump -i eth0 -n arp`
- `strace` clarifies our question ...

```
recvfrom(3, "\377\377\377\377\377\377\0\32ME|\211\10\6\0\1\10\0\6\4"..
  ., 96, MSG_TRUNC, {sa_family=AF_PACKET, proto=0x806, if50, pkttype=
  PACKET_BROADCAST, addr(6)={1, 001a4d457c89}, [18]) = 60
ioctl(3, SIOCGSTAMP, 0xbfb43e70)        = 0
write(1, "16:14:50.538813 arp who-has 10.0"..., 5516:14:50.538813 arp
  who-has 10.0.53.26 tell 10.0.63.10) = 55
recvfrom(3, "\377\377\377\377\377\377\0\4v\243\330\242\10\6\0\1\10\0"..
  ., 96, MSG_TRUNC, {sa_family=AF_PACKET, proto=0x806, if50, pkttype=
  PACKET_BROADCAST, addr(6)={1, 000476a3d8a2}, [18]) = 60
ioctl(3, SIOCGSTAMP, 0xbfb43e70)        = 0
write(1, "16:14:50.624868 arp who-has 10.0"..., 5616:14:50.624868 arp
  who-has 10.0.63.53 tell 10.0.54.184) = 56
```

tcpdump, libpcap

- For every incoming frame a *recvfrom*-Syscall is executed
- What does that mean?
  - `recvfrom(...)`
  - Buffer will be copied from Userspace to Kernelspace[4]
  - Context switch (done by Scheduler / Dispatcher)
  - Buffer will be copied from Kernelspace back to Userspace[5]
  - Context switch (done by Scheduler / Dispatcher)
- ... very time intensive if done for each frame!
- ... possible frame drops for socket during high traffic

[4] `copy_from_user()`

[5] `copy_to_user()`

netsniff-ng

- High performance network sniffer
- Consists of
  - *netsniff-ng*
  - *check_packets* (client for Nagios)

netsniff-ng features

- The sniffer itself ...
- Runs in promiscuous mode
- Bypasses the complete network stack
- Uses Kernelspace Berkeley Packet Filter (`BPF`)
- Allocates 128 MB or less (probing) Kernelspace Receive Ring (`RX_RING`)
- Ring is Memory-Mapped into Userspace (so no Syscalls like `recvfrom()` needed → Zero-Copy)
- Branchfree critical path (so we won't smash the Pipeline)
- Tested on Gigabit without packet loss
- Can be run as Sysdaemon (silent, creates `UDS` Server for communication) or in foreground

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netsniff-ng features

- `netsniff-ng -d eth0 -f /etc/netsniff-ng/rules/arp.bpf -C`
- strace again, looks better now ...

```
rt_sigprocmask(SIG_BLOCK, [USR1 ALRM], NULL, 8) = 0
rt_sigprocmask(SIG_UNBLOCK, [USR1 ALRM], NULL, 8) = 0
poll([{fd=3, events=POLLIN|POLLERR, revents=POLLIN}], 1, -1) = 1
write(2, "I: ", 3I: )                          = 3
write(2, "60 bytes from 00:1a:4d:45:7c:89 "..., 5360 bytes from 00:
  1a:4d:45:7c:89 to ff:ff:ff:ff:ff:ff) = 53
rt_sigprocmask(SIG_BLOCK, [USR1 ALRM], NULL, 8) = 0
rt_sigprocmask(SIG_UNBLOCK, [USR1 ALRM], NULL, 8) = 0
poll([{fd=3, events=POLLIN|POLLERR, revents=POLLIN}], 1, -1) = 1
write(2, "I: ", 3I: )                          = 3
write(2, "60 bytes from 00:10:5a:d8:9a:a4 "..., 5360 bytes from 00:10:
  5a:d8:9a:a4 to ff:ff:ff:ff:ff:ff) = 53
```

netsniff-ng features

- `netsniff-ng -d eth0 -f /etc/netsniff-ng/rules/icmp.bpf`
- ICMP-Flooding; only 0-3% CPU usage of netsniff-ng during tests

```
I: elapsed time: 0 d, 0 h, 4 min, 45 s
I: -----------+------------------+------------------+------------------
I:            |  per sec         |  per min         |  total
I: -----------+------------------+------------------+------------------
I:   frames   |            80201 |          4696273 |         20149411
I: -----------+------------------+------------------+------------------
I:   in B     |        119622775 |       7003546464 |      30048067864
I:   in KB    |           116819 |          6839400 |         29343816
I:   in MB    |              114 |             6679 |            28656
I:   in GB    |                0 |                6 |               27
I: -----------+------------------+------------------+------------------
[...]
I: 23724545 frames incoming
I: 23724545 frames passed filter
I: 0 frames failed filter (due to out of space)
I: captured frames: 23724545, captured bytes:
   35377999772 [34548827 KB, 33739 MB, 32 GB]
```

check_packets features

- Is a Unix Domain Socket Client for netsniff-ng
- Fetches collected network statistics at runtime via `UDS` inode
- `-n` option for creating Nagios one-liner → Performance data
- Simple Nagios integration with `NRPE` or `check_by_ssh`

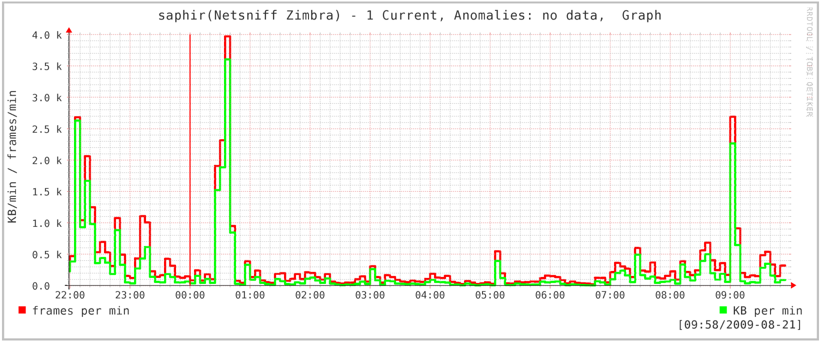
Integration into Nagios

Integration into Nagios

- Runs 24x7 on MPI router (DMZ ⇔ Router ⇔ Internet)
- 6 instances running with following BPFs:
  - All
  - HTTP
  - Broadcast
  - SSH
  - Webserver
  - Mailserver traffic
- Data will be passed via check_by_ssh[6] (Port 22) through our internal Firewall to our Nagios server
- Visualization realized by NagiosGrapher via Round Robin Databases

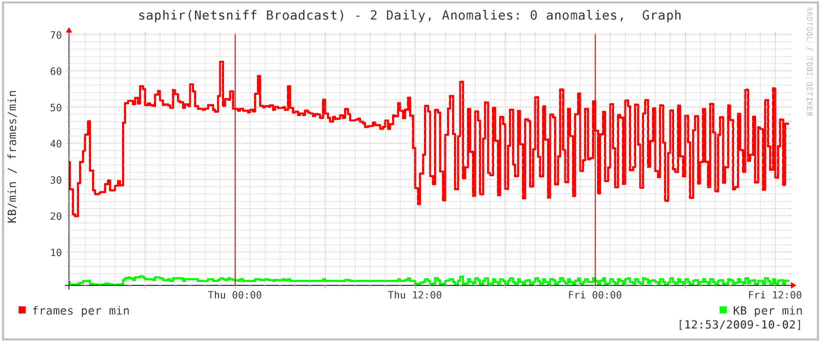
[6] NRPE inappropriate in our case

Some results



({Sec|}IMAP, {Sec|}SMTP, POP3, HTTP traffic to our Zimbra mailserver)

Some results



(Broadcast traffic)

Data analysis

Assumptions about our data ...

Assumptions

- Generally our monitored processes equal Stochastic processes
- Incoming anomalies itself are regarded as Poisson processes
- A single data point has ...
  - Baseline („intercept“) or irregular component
  - Linear trend („slope“) component
  - Seasonal trend (at least one)
- We assume components are additive

Anomaly detection techniques

Holt-Winters-Forecasting (and some improvements)

Holt-Winters-Forecasting

- Based on exponential smoothing (recent data have higher weights than older ones): $\hat{y}_{t+1} = \alpha y_t + (1-\alpha)\hat{y}_t$ with $0 < \alpha < 1$
- Decomposition of time series into components with triple exponential smoothing technique
- Multiplicative and additive versions
- Forecast of the near future (with $+/-$ deviation), check if actual value falls into expected interval (if not: anomaly after breaking thresholds)

Holt-Winters-Forecasting

What the math model looks like:

- **Prediction:**

  $\hat{y}_{t+1} = a_t + b_t + c_{t+1-m}$

  $$\begin{aligned} a_t &= \alpha(y_t - c_{t-m}) + (1-\alpha)(a_{t-1} + b_{t-1}) \\ b_t &= \beta(a_t - a_{t-1}) + (1-\beta)b_{t-1} \\ c_t &= \gamma(y_t - a_t) + (1-\gamma)c_{t-m} \end{aligned}$$

  Baseline,

  Linear trend,

  Seasonal trend

- **Confidence band coefficient:**

  $d_t = \gamma|y_t - \hat{y}_t| + (1-\gamma)d_{t-m}$

  $0 < \alpha, \beta, \gamma < 1$

  m: Len season

- **Confidence band itself:**

  $\mathbb{I}(\hat{y}_t - \delta_- * d_{t-m}, \hat{y}_t + \delta_+ * d_{t-m}) \quad 2 < \delta_-, \delta_+ < 3$

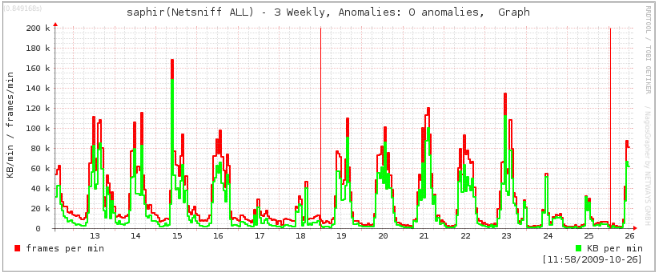
- **Sliding window as threshold for anomalies**

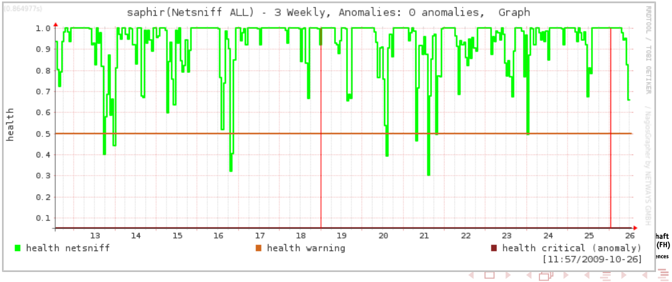
Holt-Winters-Forecasting

Possible improvements:

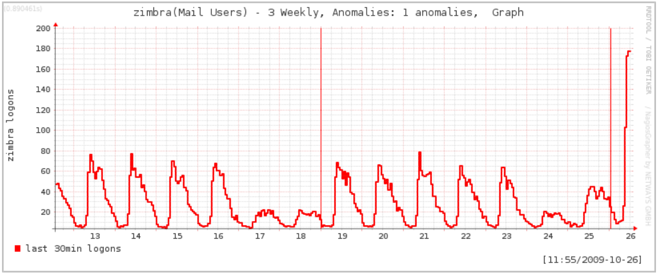
- Double seasonality (periods of week, day)
  - Up to now only single seasonality (day) → parameter disturbances of passing business days into non-business days and vice versa
- Parameter stabilization via Kalman filter [Gelper et al. 2007]
  - Will make parameters more robust towards interferences of anomalies
- Miller extension for improving prediction of low traffic values [Miller 2007]
  - Longterm zero-values decreases confidence band to minimal width → slight payload variance will result in anomaly even though it isn't

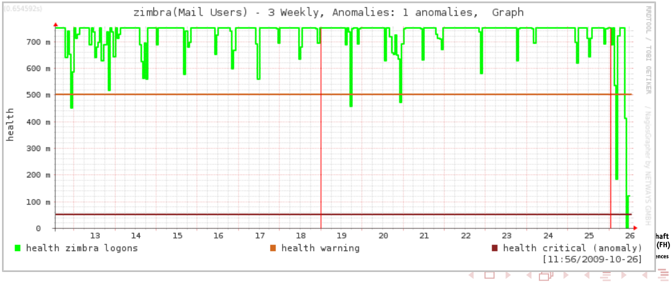
Holt-Winters-Forecasting, Results (all traffic)





Holt-Winters-Forecasting, Results (active Zimbra users)



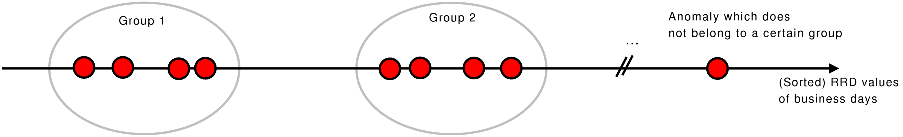


Clusteranalysis approach

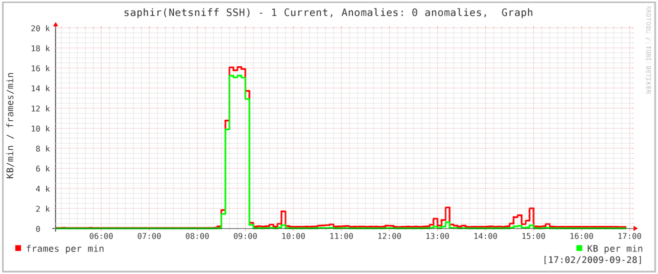
Clusteranalysis approach

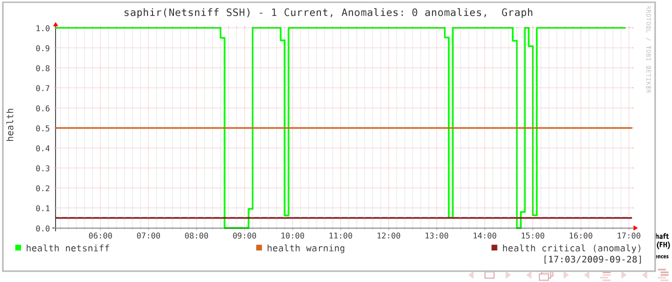
- Idea: one-dimensional grouping of data points to interval bands in order to separate anomalous from normal behaviour
- Segregation of business days and non-business days
- Grouping threshold set by standard deviation of Poisson Process (adapted with coeffcient)
- Groups consist of at least 25 per cent of data points (as per definition)

Clusteranalysis approach

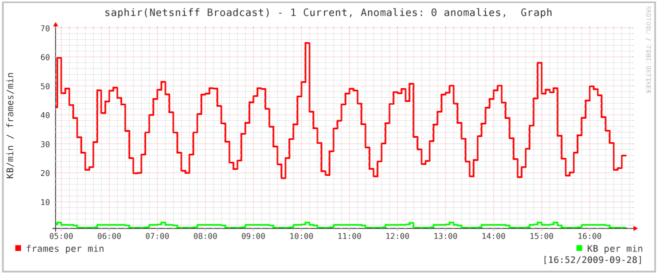


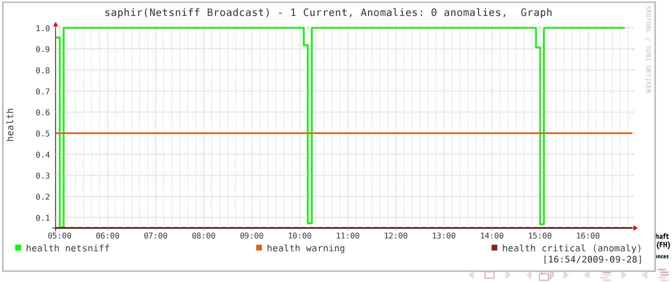
Clusteranalysis, Results (SSH traffic)





Clusteranalysis, Results (Broadcast traffic)





Interface to NagiosGrapher

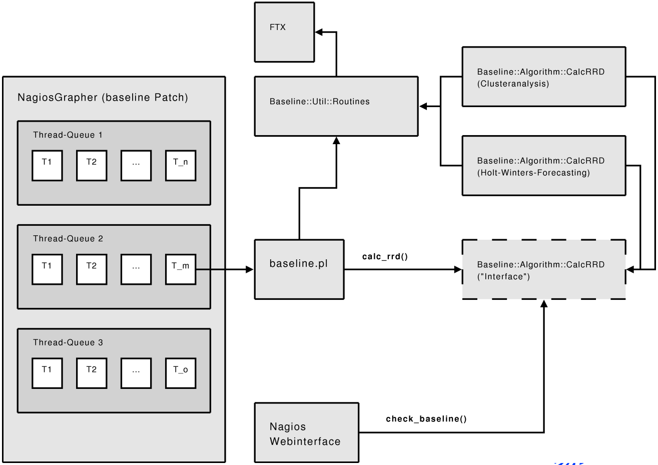
Interface to NagiosGrapher

- Three thread queues filled during NGs **collect2.pl** runtime (*patched against nagiosgrapher (1.6.1rc5-6), Debian Lenny (stable)*)
- Detached threads check for anomalies according to given algorithm (start **baseline.pl** delegate after RRD update)
- Module **Baseline::Algorithm::CalcRRD** with **calc_rrd()** and **check_baseline()** implemented for specific algorithm

Interface to NagiosGrapher

- Algorithms swappable during runtime without payload loss!
- Anomaly information on Nagios ‘Service Detail‘ page
- **Baseline::Util::Routines** contain helper routines for CalcRRD implementation (as **fetch_stepping()**, **fetch_lastupdate()**, **fetch_table()**, ...)

Interface to NagiosGrapher

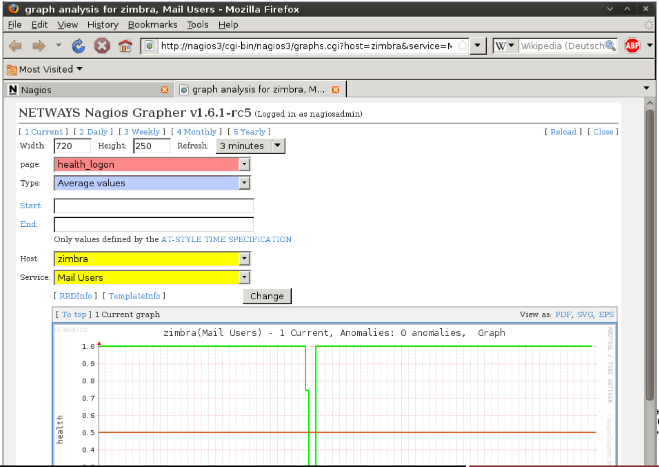

FTX
NagiosGrapher (baseline Patch)
Thread-Queue 1
T1
T2
...
T_n
Thread-Queue 2
T1
T2
...
T_m
Thread-Queue 3
T1
T2
...
T_o
Baseline::Util::Routines
Baseline::Algorithm::CalcRRD (Clusteranalysis)
Baseline::Algorithm::CalcRRD (Holt-Winters-Forecasting)
baseline.pl
calc_rrd()
Baseline::Algorithm::CalcRRD ("Interface")
Nagios Webinterface
check_baseline()

NagiosGrapher GUI, config integration

```
define ngraph{
        service_name                    Netsniff *
        graph_log_regex                 .*per\sminute:\s+([0-9\.]+)\sframes
        graph_value                     pktfr
        graph_units                     frames/min
        graph_legend                    frames per min
        rrd_plottype                    LINE2
        rrd_color                       FF0000
        hide                            no
        page                            data
}
define ngraph{
        service_name                    Netsniff *
        type                            BASELINE      <-- unknown, will be ignored within perfdata parsing
        graph_value                     pktfrbase
        graph_units                     health
        graph_legend                    health temperature
        rrd_plottype                    LINE2
        rrd_color                       00ff00
        hide                            no
        page                            health_frames
}
```

Interface to NagiosGrapher

- Two (or more) pages per Service (‘data‘, ‘health_*‘)
- Actual data (payload, anomaly) still separated


graph analysis for zimbra, Mail Users - Mozilla Firefox
File Edit View History Bookmarks Tools Help
http://nagios3/cgi-bin/nagios3/graphs.cgi?host=zimbra&service=M
Wikipedia (Deutsch
Most Visited
Nagios
graph analysis for zimbra, M...

NETWAYS Nagios Grapher v1.6.1-rc5 (Logged in as nagiosadmin)

[1 Current] [2 Daily] [3 Weekly] [4 Monthly] [5 Yearly]
[Reload] [Close]

Width: 720 Height: 250 Refresh: 3 minutes

page: health_logon

Type: Average values

Start:

End:

Only values defined by the AT-STYLE TIME SPECIFICATION

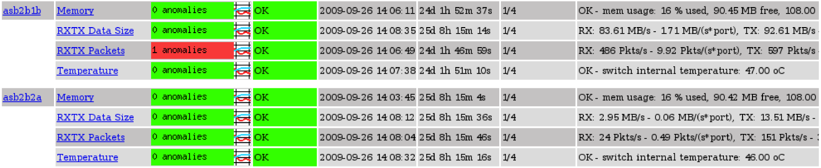
Host: zimbra

Service: Mail Users

[RRDInfo] [TemplateInfo]
Change
[To top] 1 Current graph
View as: PDF, SVG, EPS
(0.460871s)
zimbra(Mail Users) - 1 Current, Anomalies: 0 anomalies, Graph
1.0
0.9
0.8
0.7
0.6
0.5
0.4
health
RRDTOOL / TOBI OETIKER
/ NagiosGrapher

Interface to NagiosGrapher

- Integration into Nagios ‘Service Detail‘ page
- **check_baseline()** part of **Baseline::Algorithm::CalcRRD** called



asb2b1b	Memory	0 anomalies		OK	2009-09-26 14:06:11	24d 1h 52m 37s	1/4	OK - mem usage: 16 % used, 90.45 MB free, 108.00
	RXTX Data Size	0 anomalies		OK	2009-09-26 14:08:35	25d 8h 15m 14s	1/4	RX: 83.61 MB/s - 1.71 MB/(s*port), TX: 92.61 MB/s -
	RXTX Packets	1 anomalies		OK	2009-09-26 14:06:49	24d 1h 46m 59s	1/4	RX: 486 Pkts/s - 9.92 Pkts/(s*port), TX: 597 Pkts/s -
	Temperature	0 anomalies		OK	2009-09-26 14:07:38	24d 1h 51m 10s	1/4	OK - switch internal temperature: 47.00 oC
asb2b2a	Memory	0 anomalies		OK	2009-09-26 14:03:45	25d 8h 15m 4s	1/4	OK - mem usage: 16 % used, 90.42 MB free, 108.00
	RXTX Data Size	0 anomalies		OK	2009-09-26 14:08:12	25d 8h 15m 36s	1/4	RX: 2.95 MB/s - 0.06 MB/(s*port), TX: 13.51 MB/s -
	RXTX Packets	0 anomalies		OK	2009-09-26 14:08:04	25d 8h 15m 46s	1/4	RX: 24 Pkts/s - 0.49 Pkts/(s*port), TX: 151 Pkts/s -
	Temperature	0 anomalies		OK	2009-09-26 14:08:32	25d 8h 15m 16s	1/4	OK - switch internal temperature: 46.00 oC

Trend analysis

Levenberg-Marquardt

Levenberg-Marquardt

- Non-linear fitting algorithm
- Fits a math model (e.g. $f(x) := acos(bx) + bsin(ax) + c$) into a series of data points with minimal residuals (parameter search → $\{a, b, c\}$)
- More ‘stable‘ in finding local minimum (even with a bad chosen start vector) than Gauss-Newton method (with ‘lambda decay‘)
- Non-linearity approximated by iterative solving of linear equation systems (Taylor series)
- Note: quality of the fit depends on your defined model!

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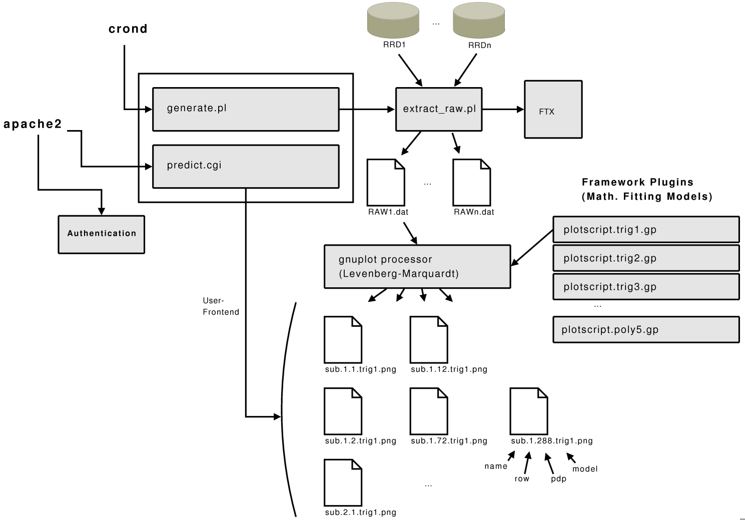
REA[7]-Framework

[7] RRD extrapolation and analysis

REA-Framework

- NG-independet script collection (works with all possible RRDs)
- **generate.pl**
  - Called via nightly cronjob
  - Automatically extracts RRD payload (extract_raw.pl) → triple: (timestamp, normalized idx, data value)
  - Runs configured plugins via gnuplot processor
  - Generates graph images (if possible) and copies them into WWW-dir
- **predict.cgi**
  - User interface
  - User assigns configured ‘subject‘ (e.g. host service) to ‘analysis type‘ (e.g. monomial extrapolation)
  - All RRA specific graphs with chosen fits are shown

REA-Framework



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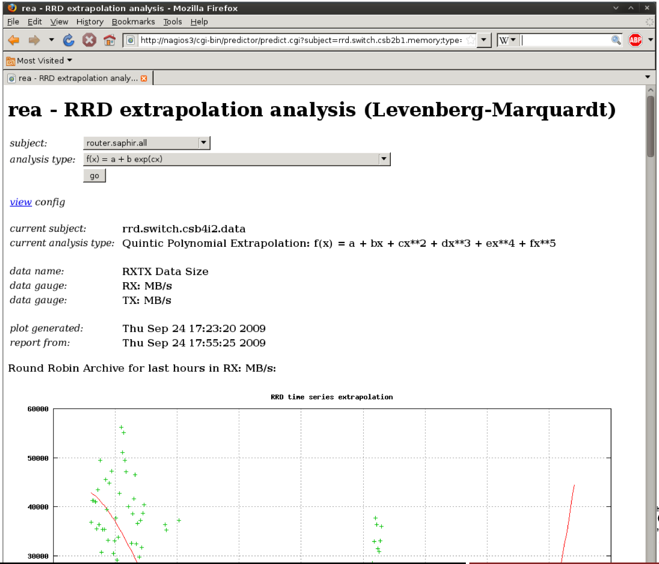
REA-Framework, plugin for Monomial extrapolation

```
#!/usr/bin/gnuplot

FIT_LIMIT = 1e-6
FIT_MAXITER = 80

f(x) = a * (x - b)**n + c
fit f(x) "exp.dat" using 2:3 via a, b, c, n

set grid
set title "RRD time series extrapolation"
set timefmt "%s"
set xdata time
set format x "%d.%m.%Y, %H/%M"
set xlabel " "
set ylabel " "
set xtics rotate by 90 scale 0
set key below

plot "< cat exp.dat fore.dat" using 1:(f($2)) title "best \'a * (x - b)^n + c\' fit" with lines, \
     "exp.dat" using 1:3 title "time series data" with points

set term png size 1024, 768
set output "plot.png"
replot

set term dumb
```

REA-Framework, frontend


rea - RRD extrapolation analysis - Mozilla Firefox
File Edit View History Bookmarks Tools Help
http://nagios3/cgi-bin/predictor/predict.cgi?subject=rrd.switch.csb2b1.memory;type=
Most Visited
rea - RRD extrapolation analy...

rea - RRD extrapolation analysis (Levenberg-Marquardt)

subject: router.saphir.all
analysis type: f(x) = a + b exp(cx)
go

view config

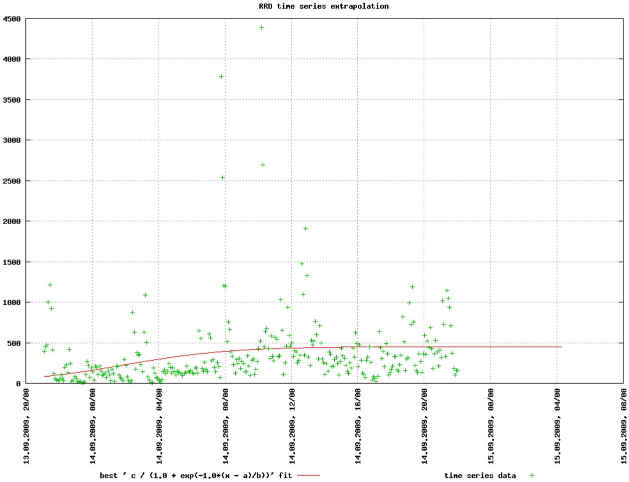
current subject: rrd.switch.csb4i2.data
current analysis type: Quintic Polynomial Extrapolation: f(x) = a + bx + cx**2 + dx**3 + ex**4 + fx**5

data name: RXTX Data Size
data gauge: RX: MB/s
data gauge: TX: MB/s

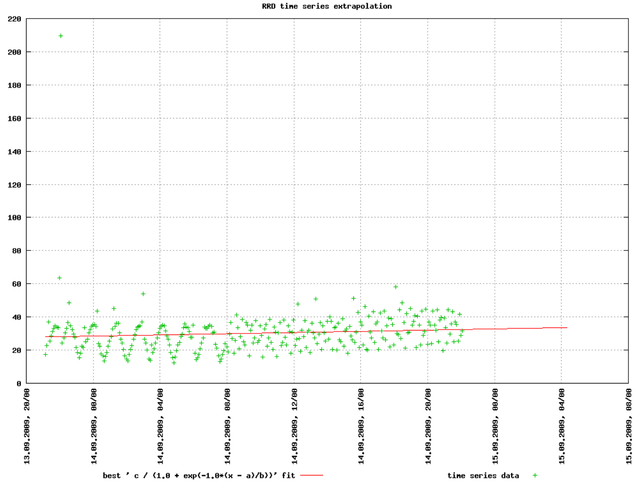
plot generated: Thu Sep 24 17:23:20 2009
report from: Thu Sep 24 17:55:25 2009

Round Robin Archive for last hours in RX: MB/s:

REA-Framework, Results (Traffic to webserver, KB/min)



REA-Framework, Results (Broadcast traffic, Frames/min)



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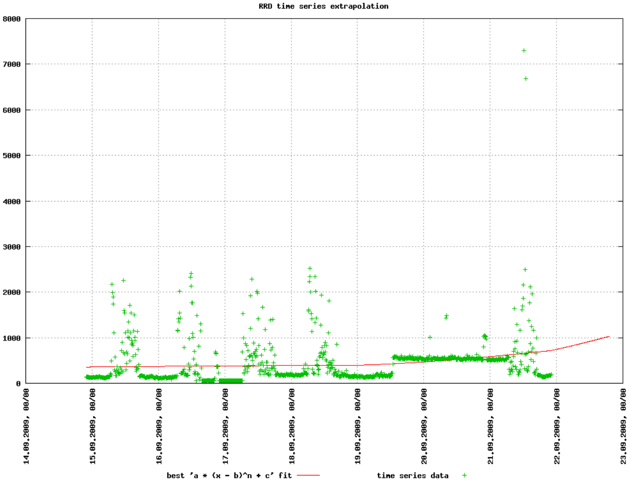
REA-Framework, Results (SSH traffic, Frames/min)



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MAX-PLANCK-GESELLSCHAFT

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Links

- **Thesis:** http://edoc.mpg.de/437809
- **netsniff-ng:** http://netsniff-ng.googlecode.com
- **All the rest[8]:** <dborkmann@acm.org>

[8] It's still a prototype ...

Q+A?