Channel Access

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Channel Access: The EPICS Network Protocol

- Read and write Process Variables over the network.

- To many, CA is EPICS.
  - Especially if your background is w/ systems that have no IOC database.
  - "Integrate into EPICS" can mean: Talk CA on the network.

Advantages over similar Control System/IoT Protocols

- ”Zero config” for small setups, yet scales to large networks
- Distributed, no central “Name Server” or “Broker” bottleneck
- Read/write/subscribe (‘get’, ‘put’, ‘monitor’)
  - Monitor sends initial value
  - ‘put-callback’ option for assured completion
- Data types that combine value with timestamp, units, status

Since ca. 1990.
Upcoming alternative: PV Access

Consider a 'news' website…

- People create web pages with news
- http:// serves them
  - Doesn't mean you can list all the people, or get the color of their socks
  - People might change
  - Some pages are created by programs, *they don't wear socks!*

- Records on IOCs provide data
- Channel Access serves them
  - Doesn't mean you can list all records
  - IOCs might change
  - Some channels are provided by python, LabVIEW, …, there are no records!

Keep in mind

- The protocol http:// is different from the people who create web sites

- The Channel Access (and PV Access) protocol is different from the IOCs and records

This 'decoupling' has proven essential but is often forgotten !

What is a Process Variable?

Good question!

"A named piece of data with attributes”

Consider this record:

```
record(calc, "t1:calcExample")
{
        field(DESC, "Sawtooth Ramp")
        field(SCAN, "1 second")
        field(CALC, "(A<10)?(A+1):0")
        field(INPA, "t1:calcExample.VAL")
}
```

What is a PV, given that record?

- "t1:calcExample"
  - PV for the current value of the record.
  - Number 0…10, changes each second.
- "t1:calcExample.DESC"
  - PV for the DESC (description) field of the record.
  - String "Sawtooth Ramp", static.
- "t1:calcExample.VAL"
  - Same as "t1:calcExample".
- “t1:calcExample.SCAN”
  - “1 second”, type enumerated, static.

Pretty much every field of a record can be a PV:

- "{record name}.{field name}"
- ".VAL" is implied when omitting field

'caget', 'caput'

'caget' command-line tool:

```
> caget t1:calcExample
t1:calcExample                 6
> caget t1:calcExample.VAL
t1:calcExample.VAL             9
> caget t1:calcExample.DESC
t1:calcExample.DESC            Sawtooth Ramp
```

'caput' allows writing:

```
> caput t1:calcExample.DESC "Howdy"
Old : t1:calcExample.DESC            Sawtooth Ramp
New : t1:calcExample.DESC            Howdy
```

'camonitor'

'camonitor' *monitors* value changes:

```
> camonitor t1:calcExample
t1:calcExample                 2006-10-06 13:26:03.332756 6
t1:calcExample                 2006-10-06 13:26:04.332809 7
t1:calcExample                 2006-10-06 13:26:05.332866 8
t1:calcExample                 2006-10-06 13:26:06.332928 9
t1:calcExample                 2006-10-06 13:26:07.332981 10
t1:calcExample                 2006-10-06 13:26:08.333034 0
t1:calcExample                 2006-10-06 13:26:09.333097 1
t1:calcExample                 2006-10-06 13:26:10.333143 2
… plus one more each second…
… press Ctrl-C to stop …


> camonitor t1:calcExample.DESC
t1:calcExample.DESC            2006-10-06 13:29:12.442257 Howdy
… and then nothing …
```

AKA *publish* and *subscribe*.

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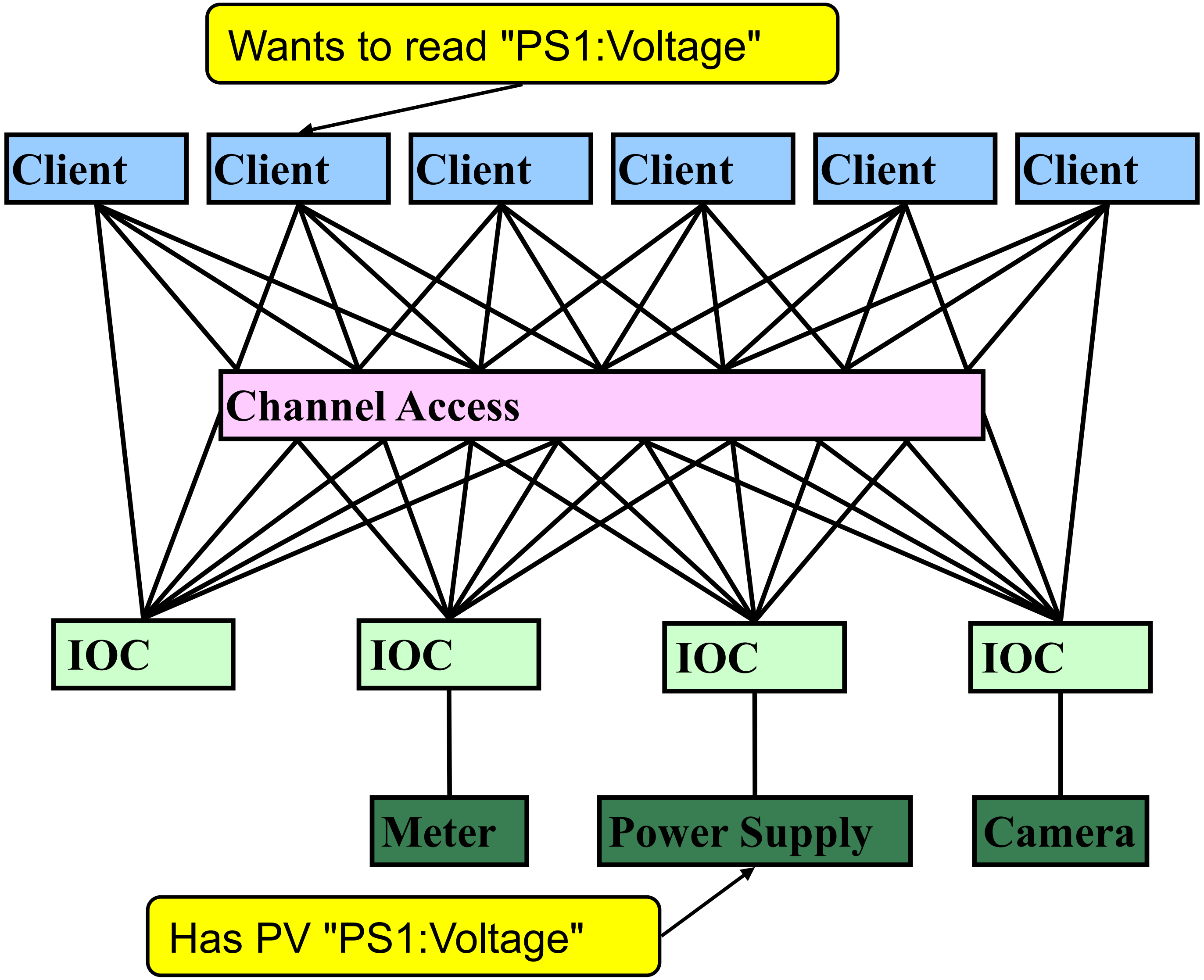
How Clients find Channels

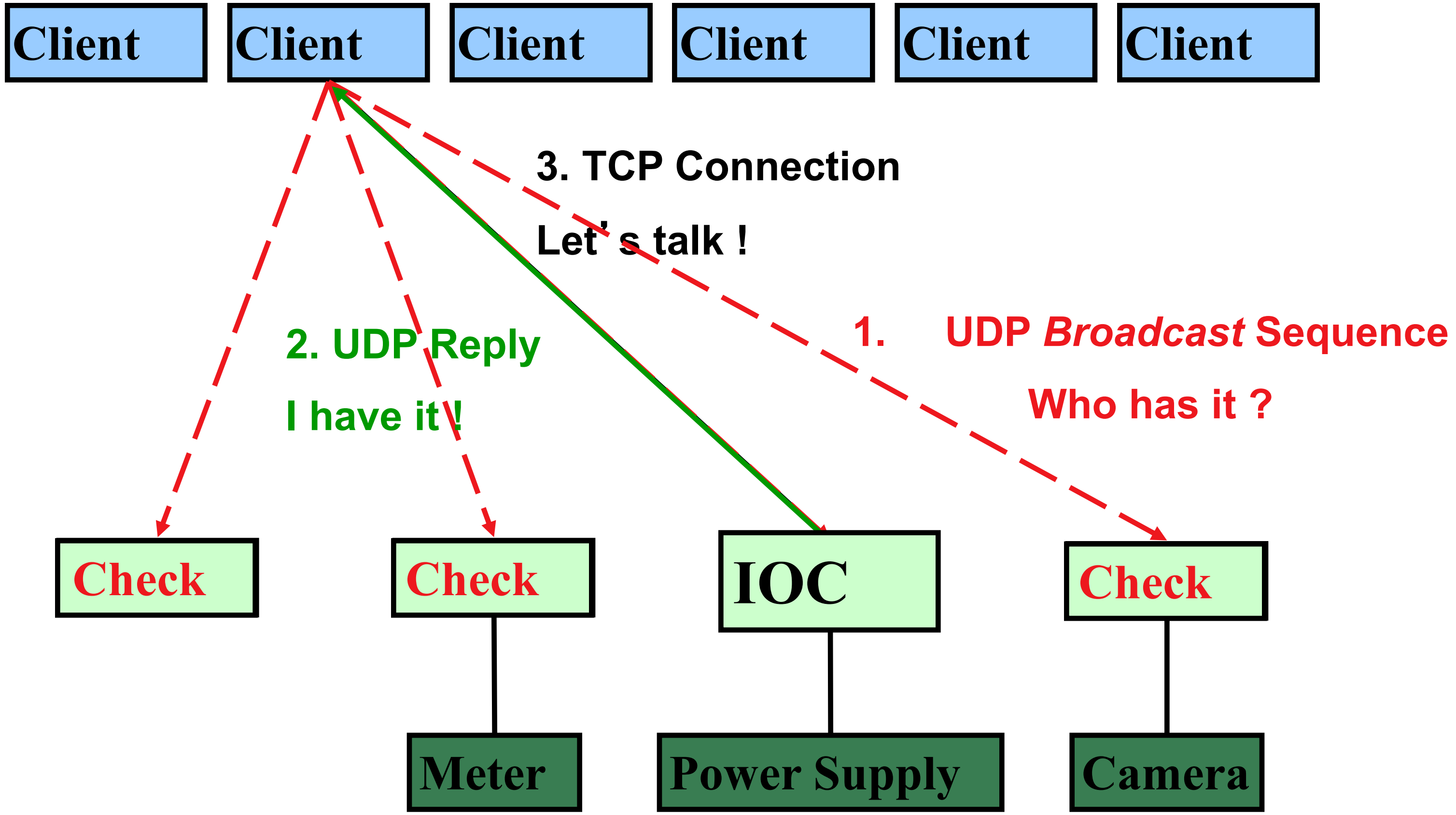

Wants to read "PS1:Voltage"

Has PV "PS1:Voltage"

Internet 101

- The Internet Protocol (IP) consists of UDP and TCP
  - .. and lower level ICMP, ARP, …
- User Datagram Protocol (UDP)
  - Sends a network packet
    - from one port on one computer
    - to one or more ports on one or more other computers.
    - ..with one or more listeners on the target port
  - Fast!
  - Checksum: If the packet arrives, it's OK.
  - Not reliable: Packets get lost, arrive out-of-order, arrive more than once.
- Transmission Control Protocol (TCP)
  - Sends a stream of bytes from one port on one computer to another port on another computer, with exactly one listener on the target port
  - Reliable: Bytes arrive at the receiver in the correct order.
    - Basically, adds serial numbers to UDP packets, requesting repeats for missing packages.
  - Slower, and message boundaries get lost:
    - "Hello Fred!" might arrive as "Hel" <pause> "lo F" <pause> "red!"

Search and Connect Procedure



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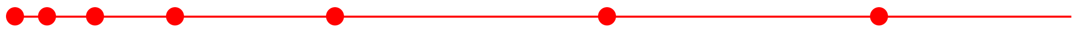
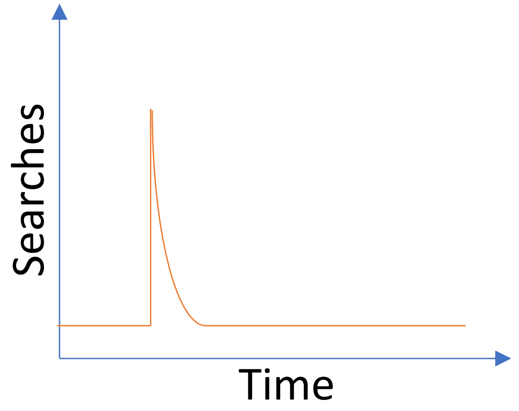
Search Request

- A search request consists of a sequence of UDP packets
  - Per default: Broadcast to the local subnet.
    - Basically plug-and-play when you get started.
  - Or to IP addresses listed in EPICS_CA_ADDR_LIST
    - Routers do not forward broadcasts!
    - You have to add 'other' subnets or specific IOCs off the local subnet to that environment variable!
  - Starts with a small interval (0.1 s)
    - Doubles each time, until reaching 5 minute intervals.
    - Stops after when it gets a response
    - Wakes again on "beacon anomaly" (details follow later)



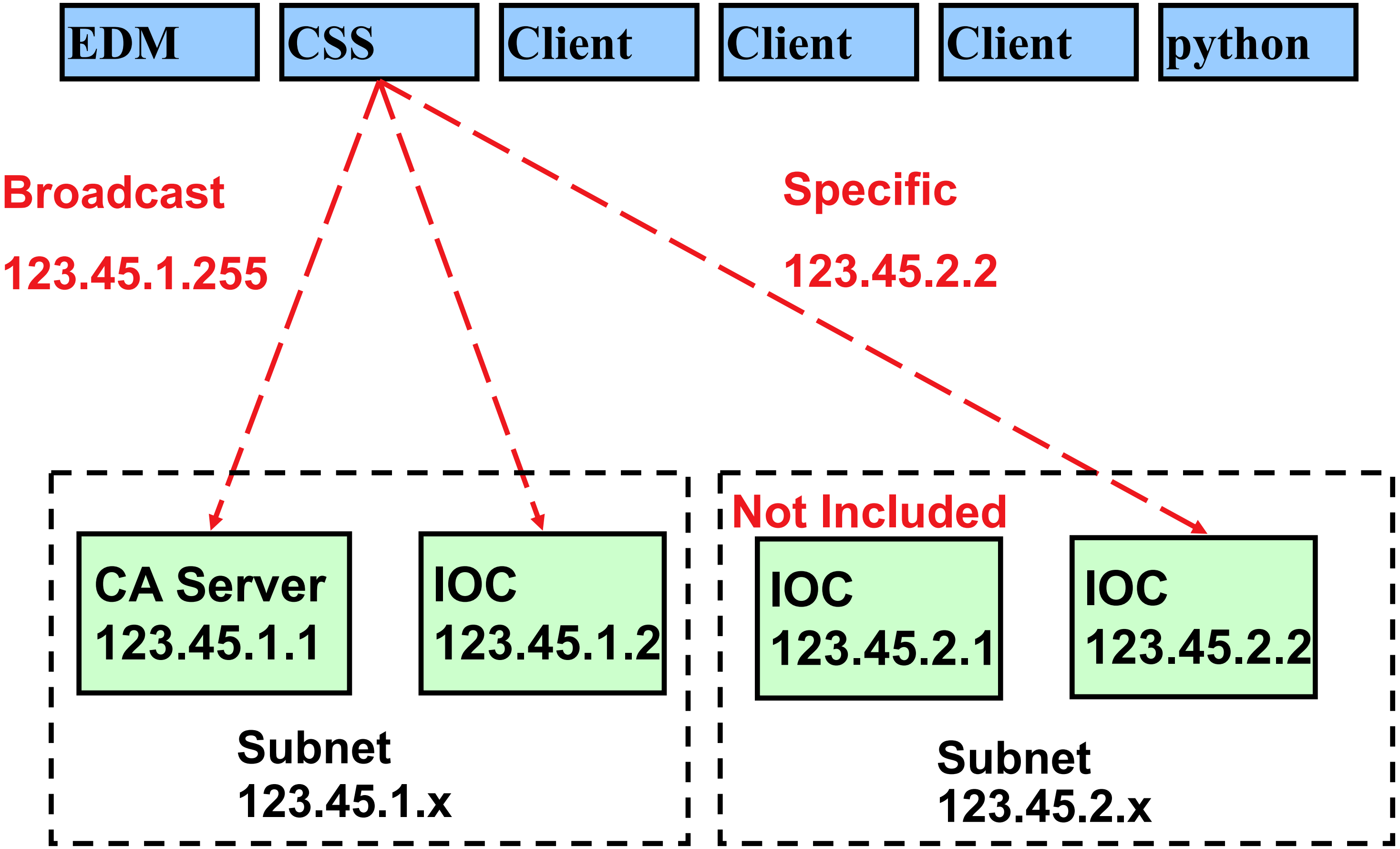


- CA Servers check each search packet
- Usually connects on the first packet or the first few
  - But non-existent PVs cause a lot of traffic
  - Try to eliminate them

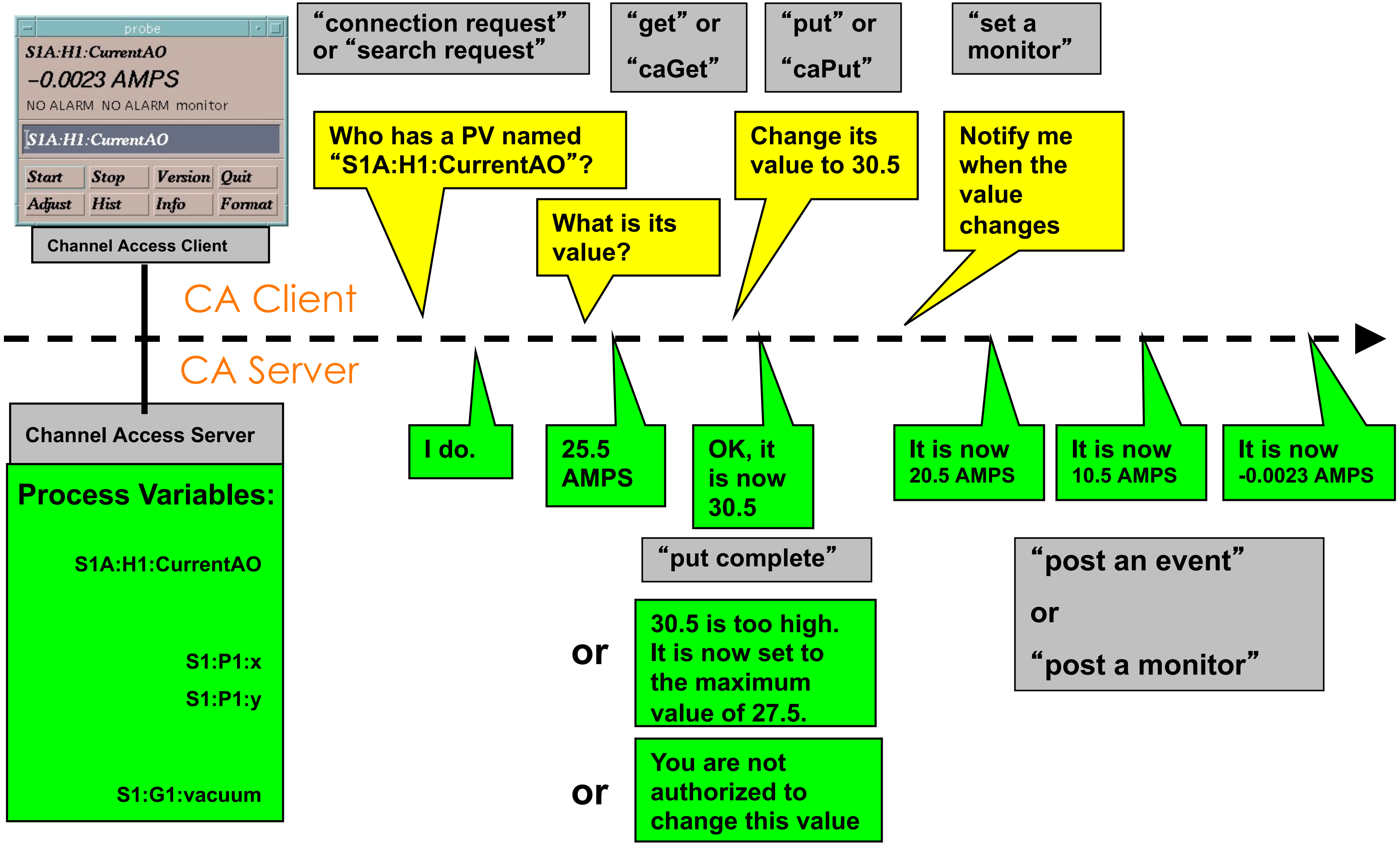
Important Environment Variables

- EPICS_CA_ADDR_LIST
  - Determines where to search
  - Is a list (separated by spaces)
    - “123.45.1.255 123.45.2.14 123.45.2.108”
  - Default is broadcast addresses of all interfaces on the host
    - Works when servers are on same subnet as Clients
  - Broadcast address
    - Goes to all servers on a subnet
    - Example: 123.45.1.255
    - Use `ifconfig –a` or `ip address` to find it on Linux
- EPICS_CA_AUTO_ADDR_LIST
  - YES: Include default addresses above in searches
  - NO: Do not search on default addresses
  - If you set EPICS_CA_ADDR_LIST, usually set this to NO

EPICS_CA_ADDR_LIST



Channel Access in One Slide



Channel Access Client

CA Client

CA Server

Channel Access Server

Process Variables:

S1A:H1:CurrentAO

S1:P1:x

S1:P1:y

S1:G1:vacuum

"connection request" or "search request"

Who has a PV named "S1A:H1:CurrentAO"?

I do.

"get" or "caGet"

What is its value?

25.5 AMPS

"put" or "caPut"

Change its value to 30.5

OK, it is now 30.5

"put complete"

or

30.5 is too high. It is now set to the maximum value of 27.5.

or

You are not authorized to change this value

"set a monitor"

Notify me when the value changes

It is now 20.5 AMPS

It is now 10.5 AMPS

It is now -0.0023 AMPS

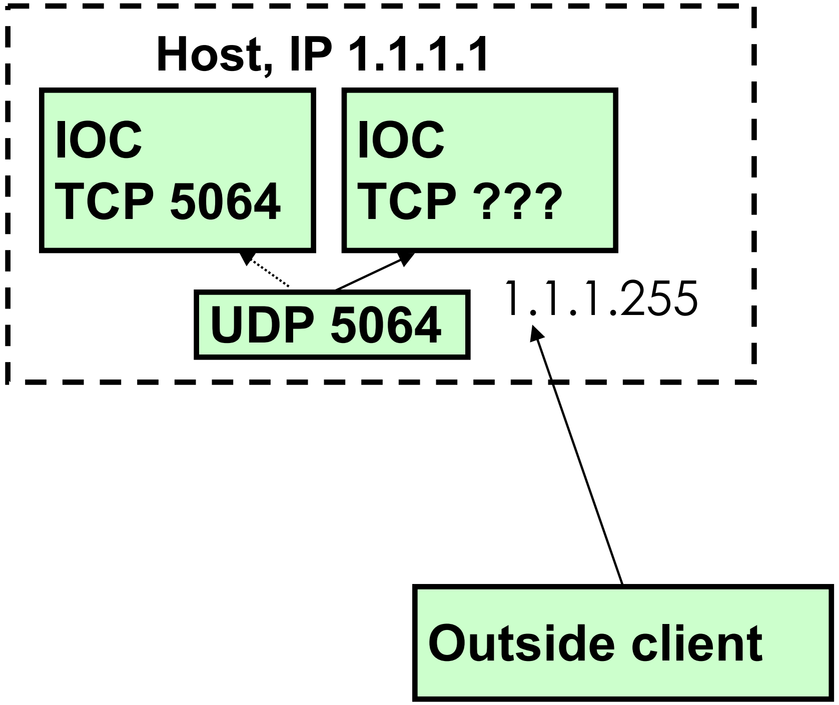
"post an event"

or

"post a monitor"

Multiple IOCs on Host

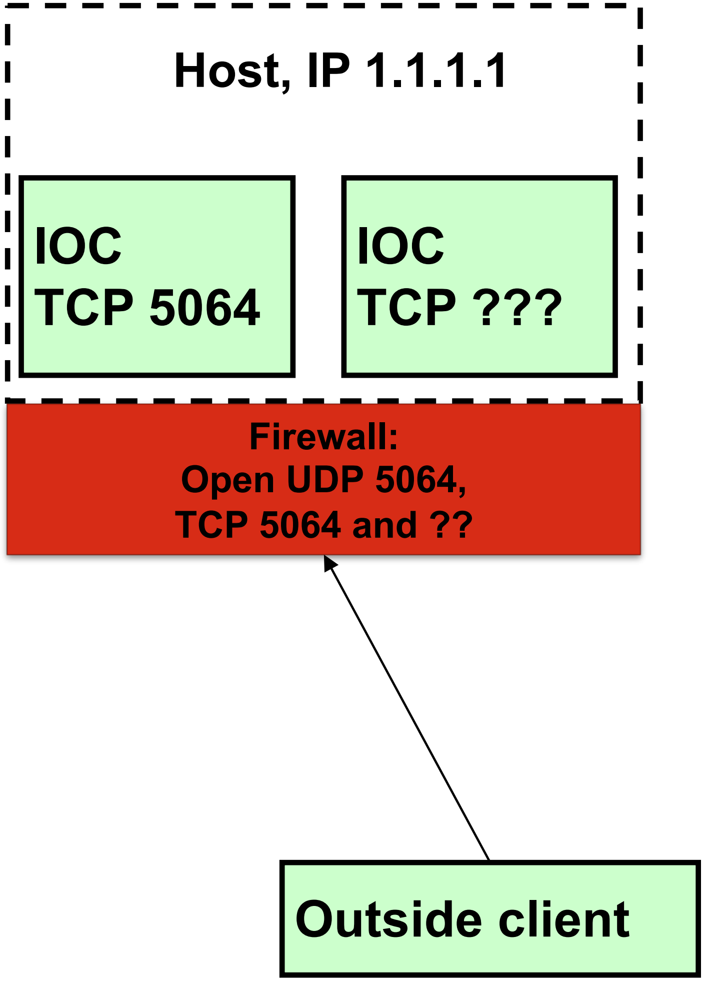
- IOCs on IP 1.1.1.1, net 1.1.1.0
  1. UDP 5064, TCP 5064
  2. UDP 5064, TCP ???
- Try to reach from other subnet
  - EPICS_CA_ADDR_LIST=1.1.1.1
    - Won’t work!
    - Quirk in network kernels:
      Only the IOC started LAST (FIRST on Windows)
      will get anything on UDP 5064
  - EPICS_CA_ADDR_LIST=1.1.1.255
    - OK. When using broadcast into subnet, all IOCs on UDP 5064
      will see search requests.



Firewall?!

- IOCs on IP 1.1.1.1, subnet 1.1.1.0
  - UDP 5064, TCP 5064
  - UDP 5064, TCP ???
  - EPICS_CA_ADDR_LIST=1.1.1.255
- Firewall cannot open unpredictable TCP ???
- Likely to block broadcasts

- Need to run CA Gateway:
  - Firewall allows access to CAGateway
  - CAGateway uses broadcast inside subnet



Handling of Network Interruptions

No Network is up 100%, so CA was designed to handle this:

- TCP connection closed by server?
  - Notify client code about problem
    - Operator displays tend to indicate this.
  - Client sends new search requests.
- No data nor beacon from server for 30 sec.?
  - Client sends “Are you there?” query
  - If no response for 5 sec, also notify client code, but TCP connection is kept open to avoid network storms.
  - If server eventually sends data: OK. Otherwise, we're waiting until the OS cuts the TCP connection (~hours).

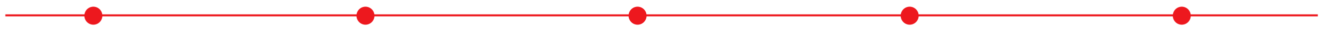
Beacons

- Assume all is fine, we are connected, but the data simply doesn't change.
  - How do we know the server is still OK?

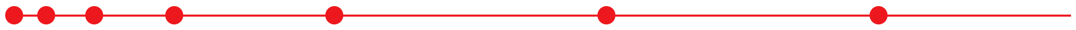
- Assume we searched for a PV, didn't get any response for ~8 minutes.
  - How do we learn about a new CA server starting up which might have the missing PV? What triggers renewed search requests?

Beacons!

- UDP broadcast packet sent by a CA Server
- When it is healthy, each Server broadcasts a UDP beacon at regular intervals (like a heartbeat)
  - EPICS_CA_BEACON_PERIOD, 15 s by default



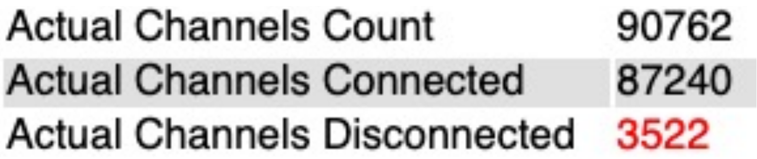
- When it is coming up, each Server broadcasts a startup sequence of UDP beacons
  - Starts with a small interval (~2 ms)
  - Interval doubles each time until reaching 15 sec



- Clients monitor the beacons
  - Receive beacons: Server is OK.
  - Receive new beacons at changing intervals: Beacon “anomaly”, new CA server, restart searches.

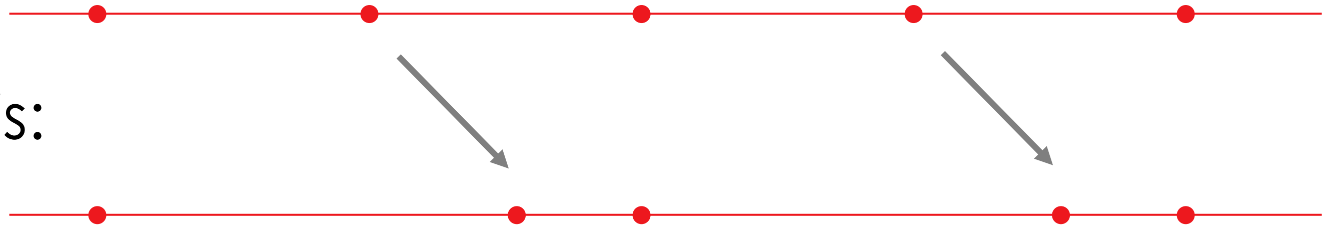
Beacon: Seemed like a good idea, but…

- Archive setups may have many missing PVs



Actual Channels Count	90762
Actual Channels Connected	87240
Actual Channels Disconnected	3522

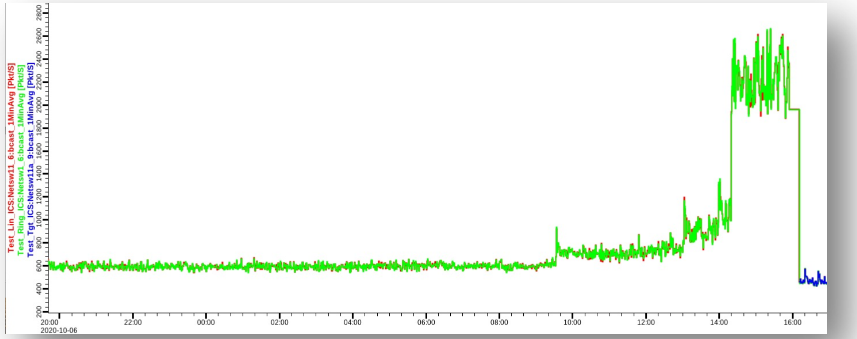
- Overloaded IOCs or network delays may change beacon pattern



.. into this:

➔ Clients with disconnected channels re-start their searches!

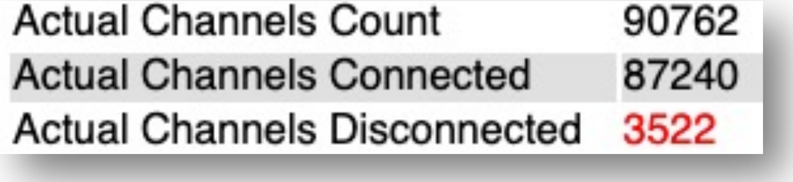
Burst in network traffic



TODO: Monitor & Maintain CA Network

- Check clients for disconnected channels
  - Archive
  - Displays
  - Run “caSnooper” to spot such clients

- Periodically run “casw”
  - Lists “beacon anomalies”
    Are those CA servers indeed “new”?



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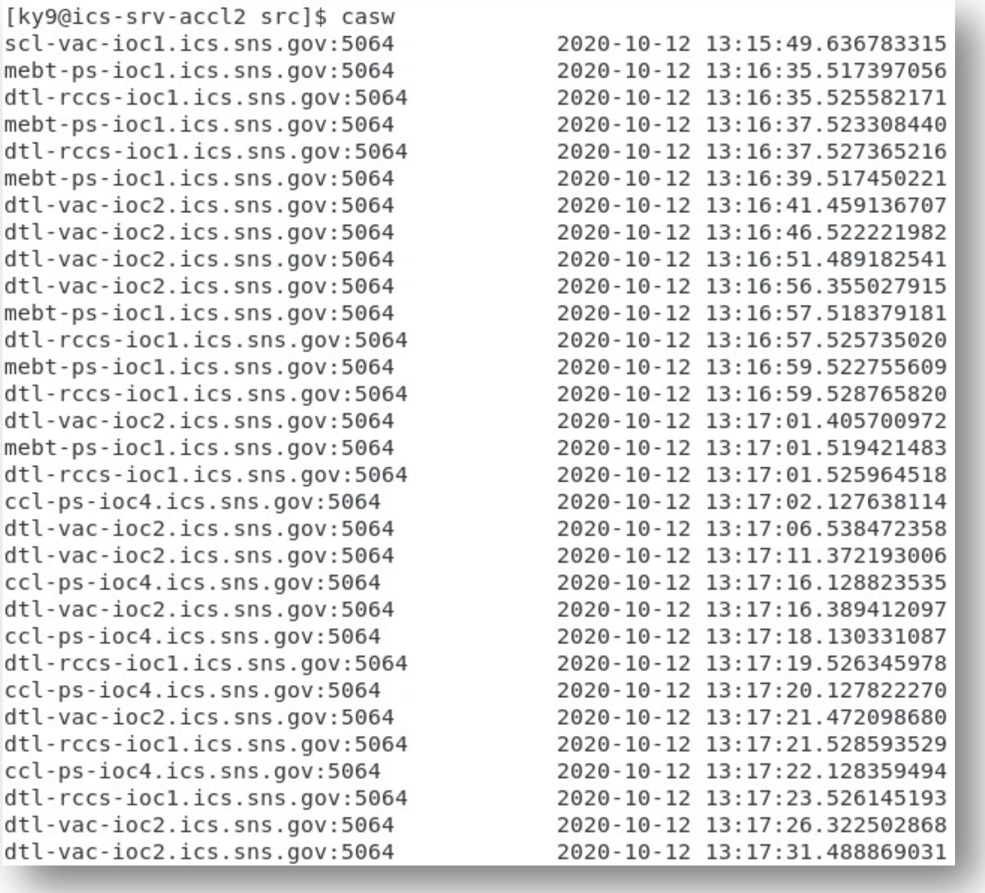
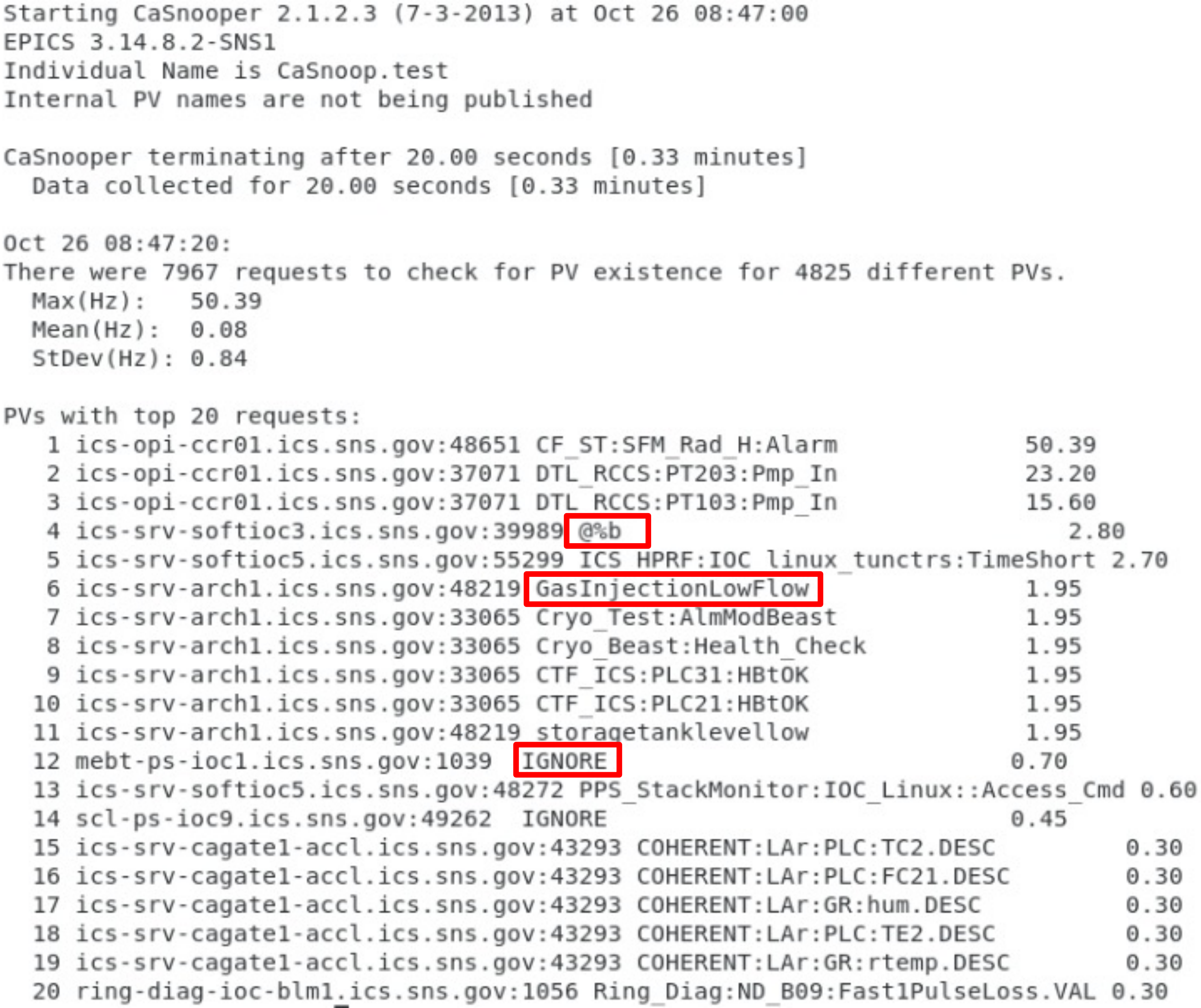


```
[ky9@ics-srv-accl2 src]$ casw
scl-vac-ioc1.ics.sns.gov:5064            2020-10-12 13:15:49.636783315
mebt-ps-ioc1.ics.sns.gov:5064            2020-10-12 13:16:35.517397056
dtl-rccs-ioc1.ics.sns.gov:5064           2020-10-12 13:16:35.525582171
mebt-ps-ioc1.ics.sns.gov:5064            2020-10-12 13:16:37.523308440
dtl-rccs-ioc1.ics.sns.gov:5064           2020-10-12 13:16:37.527365216
mebt-ps-ioc1.ics.sns.gov:5064            2020-10-12 13:16:39.517450221
dtl-vac-ioc2.ics.sns.gov:5064            2020-10-12 13:16:41.459136707
dtl-vac-ioc2.ics.sns.gov:5064            2020-10-12 13:16:46.522221982
dtl-vac-ioc2.ics.sns.gov:5064            2020-10-12 13:16:51.489182541
dtl-vac-ioc2.ics.sns.gov:5064            2020-10-12 13:16:56.355027915
mebt-ps-ioc1.ics.sns.gov:5064            2020-10-12 13:16:57.518379181
dtl-rccs-ioc1.ics.sns.gov:5064           2020-10-12 13:16:57.525735020
mebt-ps-ioc1.ics.sns.gov:5064            2020-10-12 13:16:59.522755609
dtl-rccs-ioc1.ics.sns.gov:5064           2020-10-12 13:16:59.528765820
dtl-vac-ioc2.ics.sns.gov:5064            2020-10-12 13:17:01.405700972
mebt-ps-ioc1.ics.sns.gov:5064            2020-10-12 13:17:01.519421483
dtl-rccs-ioc1.ics.sns.gov:5064           2020-10-12 13:17:01.525964518
ccl-ps-ioc4.ics.sns.gov:5064             2020-10-12 13:17:02.127638114
dtl-vac-ioc2.ics.sns.gov:5064            2020-10-12 13:17:06.538472358
dtl-vac-ioc2.ics.sns.gov:5064            2020-10-12 13:17:11.372193006
ccl-ps-ioc4.ics.sns.gov:5064             2020-10-12 13:17:16.128823535
dtl-vac-ioc2.ics.sns.gov:5064            2020-10-12 13:17:16.389412097
ccl-ps-ioc4.ics.sns.gov:5064             2020-10-12 13:17:18.130331087
dtl-rccs-ioc1.ics.sns.gov:5064           2020-10-12 13:17:19.526345978
ccl-ps-ioc4.ics.sns.gov:5064             2020-10-12 13:17:20.127822270
dtl-vac-ioc2.ics.sns.gov:5064            2020-10-12 13:17:21.472098680
dtl-rccs-ioc1.ics.sns.gov:5064           2020-10-12 13:17:21.528593529
ccl-ps-ioc4.ics.sns.gov:5064             2020-10-12 13:17:22.128359494
dtl-rccs-ioc1.ics.sns.gov:5064           2020-10-12 13:17:23.526145193
dtl-vac-ioc2.ics.sns.gov:5064            2020-10-12 13:17:26.322502868
dtl-vac-ioc2.ics.sns.gov:5064            2020-10-12 13:17:31.488869031
```

caSnooper Example

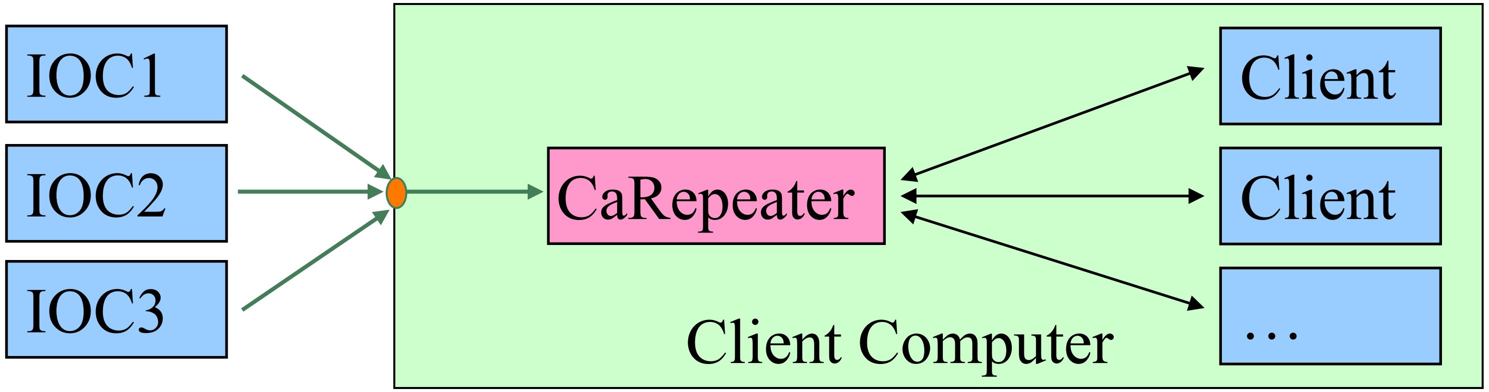
caSnooper –p20 –t20



```
Starting CaSnooper 2.1.2.3 (7-3-2013) at Oct 26 08:47:00
EPICS 3.14.8.2-SNS1
Individual Name is CaSnoop.test
Internal PV names are not being published

CaSnooper terminating after 20.00 seconds [0.33 minutes]
  Data collected for 20.00 seconds [0.33 minutes]

Oct 26 08:47:20:
There were 7967 requests to check for PV existence for 4825 different PVs.
  Max(Hz):    50.39
  Mean(Hz):   0.08
  StDev(Hz): 0.84

PVs with top 20 requests:
   1 ics-opi-ccr01.ics.sns.gov:48651 CF_ST:SFM_Rad_H:Alarm             50.39
   2 ics-opi-ccr01.ics.sns.gov:37071 DTL_RCCS:PT203:Pmp_In             23.20
   3 ics-opi-ccr01.ics.sns.gov:37071 DTL_RCCS:PT103:Pmp_In             15.60
   4 ics-srv-softioc3.ics.sns.gov:39989 @%b                               2.80
   5 ics-srv-softioc5.ics.sns.gov:55299 ICS_HPRF:IOC_linux_tunctrs:TimeShort 2.70
   6 ics-srv-arch1.ics.sns.gov:48219 GasInjectionLowFlow               1.95
   7 ics-srv-arch1.ics.sns.gov:33065 Cryo_Test:AlmModBeast             1.95
   8 ics-srv-arch1.ics.sns.gov:33065 Cryo_Beast:Health_Check           1.95
   9 ics-srv-arch1.ics.sns.gov:33065 CTF_ICS:PLC31:HBtOK               1.95
  10 ics-srv-arch1.ics.sns.gov:33065 CTF_ICS:PLC21:HBtOK               1.95
  11 ics-srv-arch1.ics.sns.gov:48219 storagetanklevellow               1.95
  12 mebt-ps-ioc1.ics.sns.gov:1039  IGNORE                            0.70
  13 ics-srv-softioc5.ics.sns.gov:48272 PPS_StackMonitor:IOC_Linux::Access_Cmd 0.60
  14 scl-ps-ioc9.ics.sns.gov:49262  IGNORE                            0.45
  15 ics-srv-cagate1-accl.ics.sns.gov:43293 COHERENT:LAr:PLC:TC2.DESC        0.30
  16 ics-srv-cagate1-accl.ics.sns.gov:43293 COHERENT:LAr:PLC:FC21.DESC       0.30
  17 ics-srv-cagate1-accl.ics.sns.gov:43293 COHERENT:LAr:GR:hum.DESC         0.30
  18 ics-srv-cagate1-accl.ics.sns.gov:43293 COHERENT:LAr:PLC:TE2.DESC        0.30
  19 ics-srv-cagate1-accl.ics.sns.gov:43293 COHERENT:LAr:GR:rtemp.DESC       0.30
  20 ring-diag-ioc-blm1.ics.sns.gov:1056 Ring_Diag:ND_B09:Fast1PulseLoss.VAL 0.30
```

caRepeater?

- Older OSs didn't allow multiple programs to listen to the same UDP port
  - They didn't see the beacons (UDP broadcasts)!
- caRepeater solves this problem
  - There is one caRepeater process per workstation
  - Clients make a TCP connection to it when they start up
  - caRepeater receives the beacons
    - EPICS_CA_REPEATER_PORT[usually 5065]
  - .. and forwards them to clients.



Issues

- CA Client does not connect
  - Check basic network connectivity.
    - Can server and client machines 'ping' each other?
    - Check EPICS_CA_ADDR_LIST if server is on different subnet.
- CA Client does not re-connect after network issue or IOC reboot
  - Use casw, wireshark: Does the client computer receive the (anomal) beacons of the rebooting IOC?
  - Check EPICS_CAS_BEACON_ADDR_LIST,since routers will not forward beacons across subnets.
  - Check if 'caRepeater' is running on the client.

What is a PV (Channel)?

- Whenever there's a CA server out there which decides to respond to a search request, that's a PV!
- iocCore responds to "{record}.{field}" searches if
  - the {record} is for a record on this IOC,
  - and the {field} is an accessible field of that record,
  - or it's the pseudo-field "RTYP" (record type).
- So every field of every record is a PV.
- But you can implement your own CA server based on the CAS library (for C++), or the pcaspy wrapper for Python, and then you decide when to respond!

Channel Properties

- Each channel comes with properties:
  - Value
    - of type string or double or int or …
    - Scalar or array
  - Time stamp
    - Up to nanosecond precision
  - Severity code
    - OK, MINOR, MAJOR, or INVALID
  - Status code to qualify the severity
    - OK, READ error, WRITE error, at HIGH limit, …
  - units, suggested display range, control limits, alarm limits.

Client interface to properties

- The available properties are fixed.
  - One cannot add a new 'color' property.
- The request types are fixed.
  - "DBR_…" types.
  - Available:
    - Just value.
    - Value with status and severity.
    - Value with status, severity and time stamp.
    - "Everything:" value, units, time, status, limits, …
  - Not available:
    - Custom combinations like value with units.
  - See `caget –h`

Records & Fields vs. Channels & Properties

- A CA client asks for the properties of a channel.
- The implementer of the CA server decides how to answer.
- The iocCore implementation maps the fields of a record to the properties of a channel.
  - Details are in the source code for the respective record type. Not always predictable or meaningful!

Example: AI record "fred"

- PV "fred" or "fred.VAL"
  - value property of channel = VAL field of record.
    - Type double, one element (scalar).
  - time property = TIME field
  - status = STAT
  - Severity = SEVR
  - units = EGU
  - Precision = PREC
  - display limit low, high = LOPR, HOPR
  - control limit low, high = LOPR, HOPR
  - alarm limits = LOLO, LOW, HIGH, HIHI

- Makes a lot of sense.
  - GUI can display the value together with units, formatted according to the precision, as e.g. "12.37 volts”.

Example: AI record "fred"

- PV "fred.SCAN"
  - value property of channel = SCAN field of record.
    - Type enumerated, values: "Passive", "1 second", ...
  - time property = TIME field?
  - status = STAT?
  - Severity = SEVR?
  - control limit low, high = 0, ??

When will ‘camonitor’ receive new value?

- When the CA server (IOC) sends a new value!
  - Analog records: VAL change >= MDEL
  - Binary records: Every change

- Assuming Client uses ‘DBE_VALUE’ subscription
  - DBE_LOG
    - Meant for archive systems. Analog record change >= ADEL
  - DBE_ALARM
    - Meant for alarm systems

Database Channel Access Link Flags

- CA: Force CA link, even though target in same IOC
- CP: For INP link, process on received CA monitor
- CPP: CP, but only if SCAN=Passive

Allows for “process record if inputs change”

Points to remember

- In 99% of the cases, CA "just works"
  - If not, check EPICS_CA_ADDR_LIST
  - If that's not it, there could be a subnet/router issue with UDP search broadcasts and beacons.
- Channel/property and Record/field are different things!
  - This decouples the CA clients from the IOC database and its record types, allowing EPICS collaborators to share CA client tools for vastly different records and databases.
  - But also means that CA clients have no idea about records nor fields.
    - Client can't know that there might be a "readback" AI that goes with a "setpoint" AO record.
    - The archiver stores channels and their properties, not a whole AI or motor record.
    - Important properties for dealing with waveform data is definitely missing (sample rate, type of data).