

The Next Frontier of Cloud Computing is in the Clouds, Literally

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Raja Sengupta

Universität Salzburg

UC Berkeley





The JAviator

javiator.cs.uni-salzburg.at

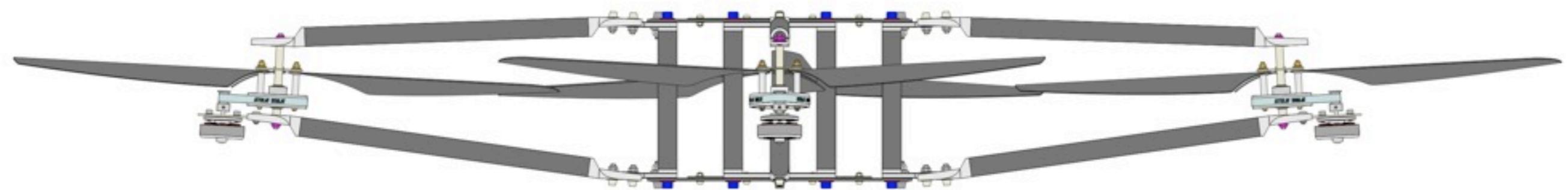
Quad-Rotor Helicopter



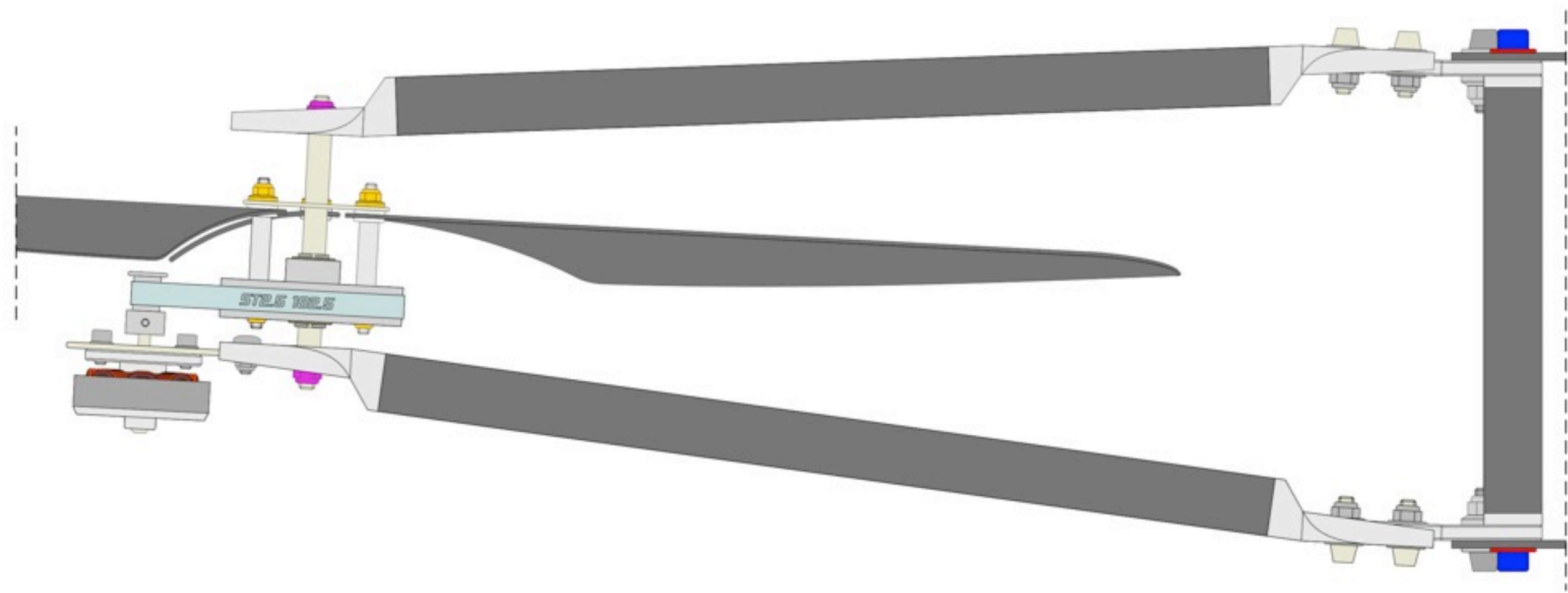
- all carbon, titanium, aluminum design
- custom motors
- 1.3m diameter
- ~2.2kg weight
- +2kg payload
- ~40min (empty)
- ~10min (full)

[AIAA GNC 2008]

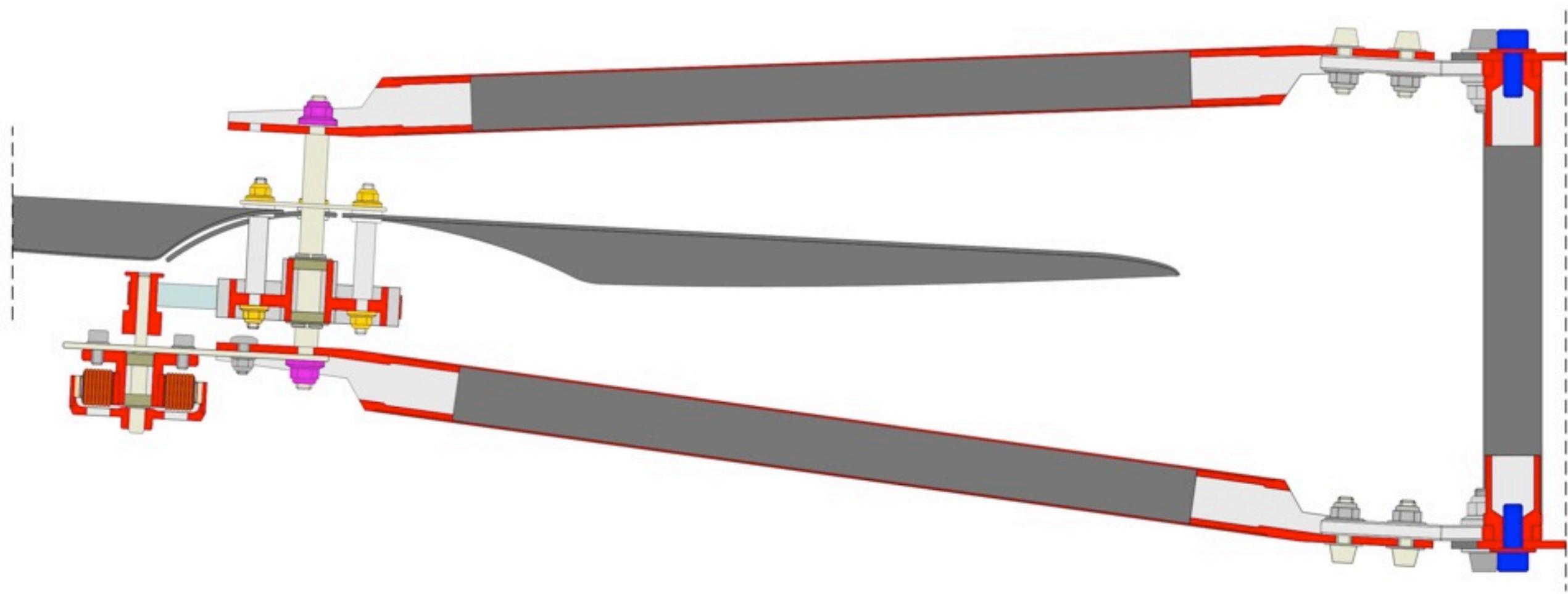
Open Source Blueprints



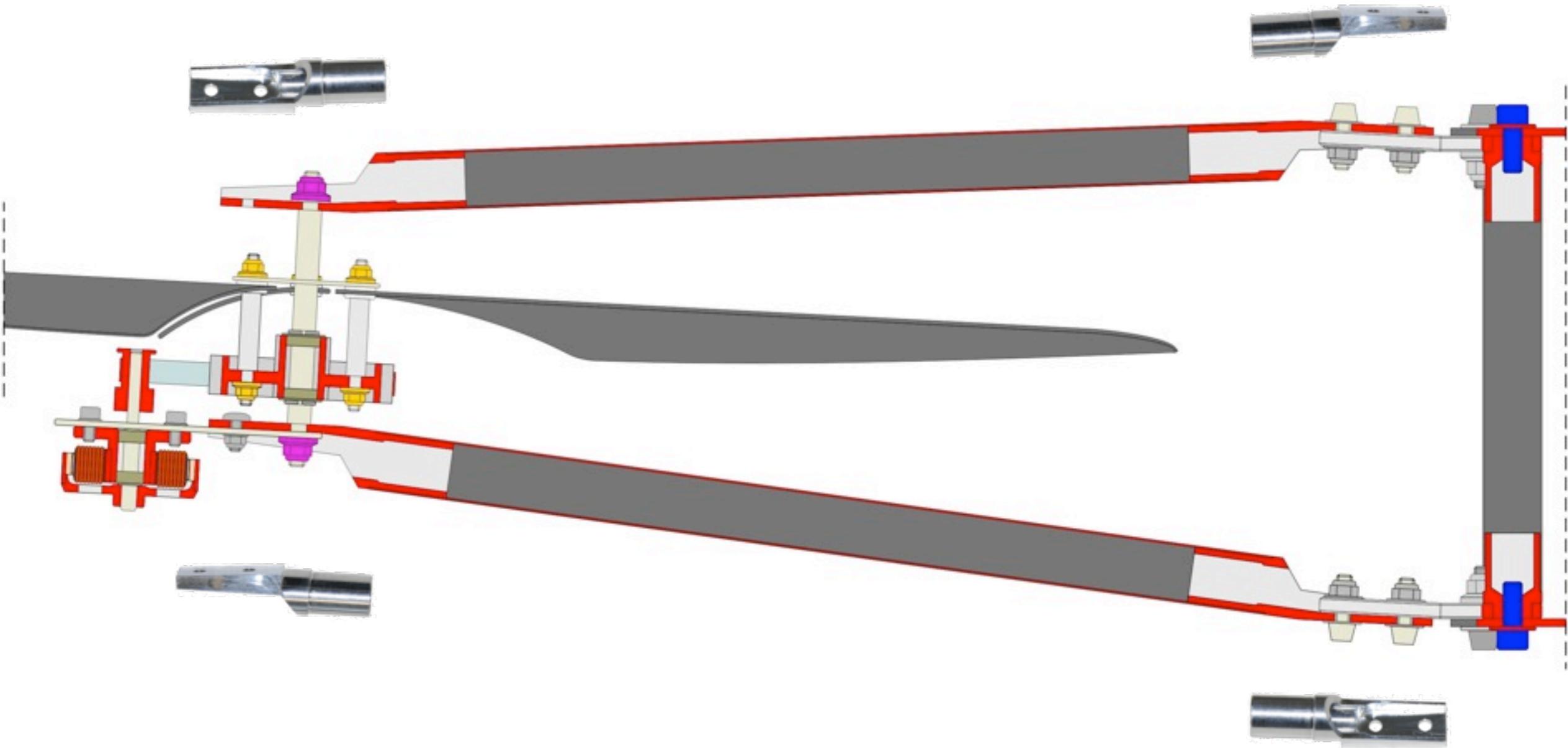
Minimal # of Different Parts



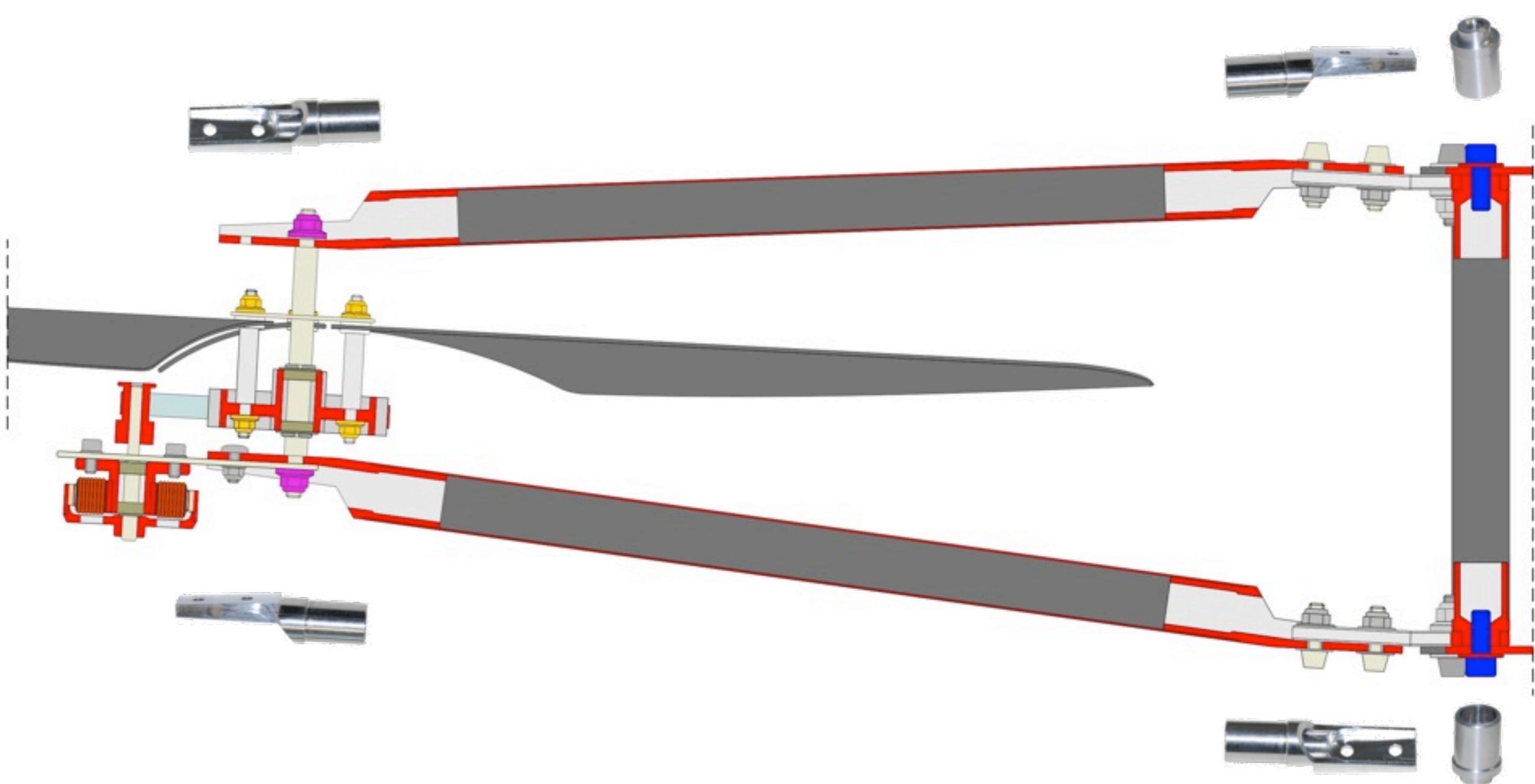
Minimal # of Different Parts



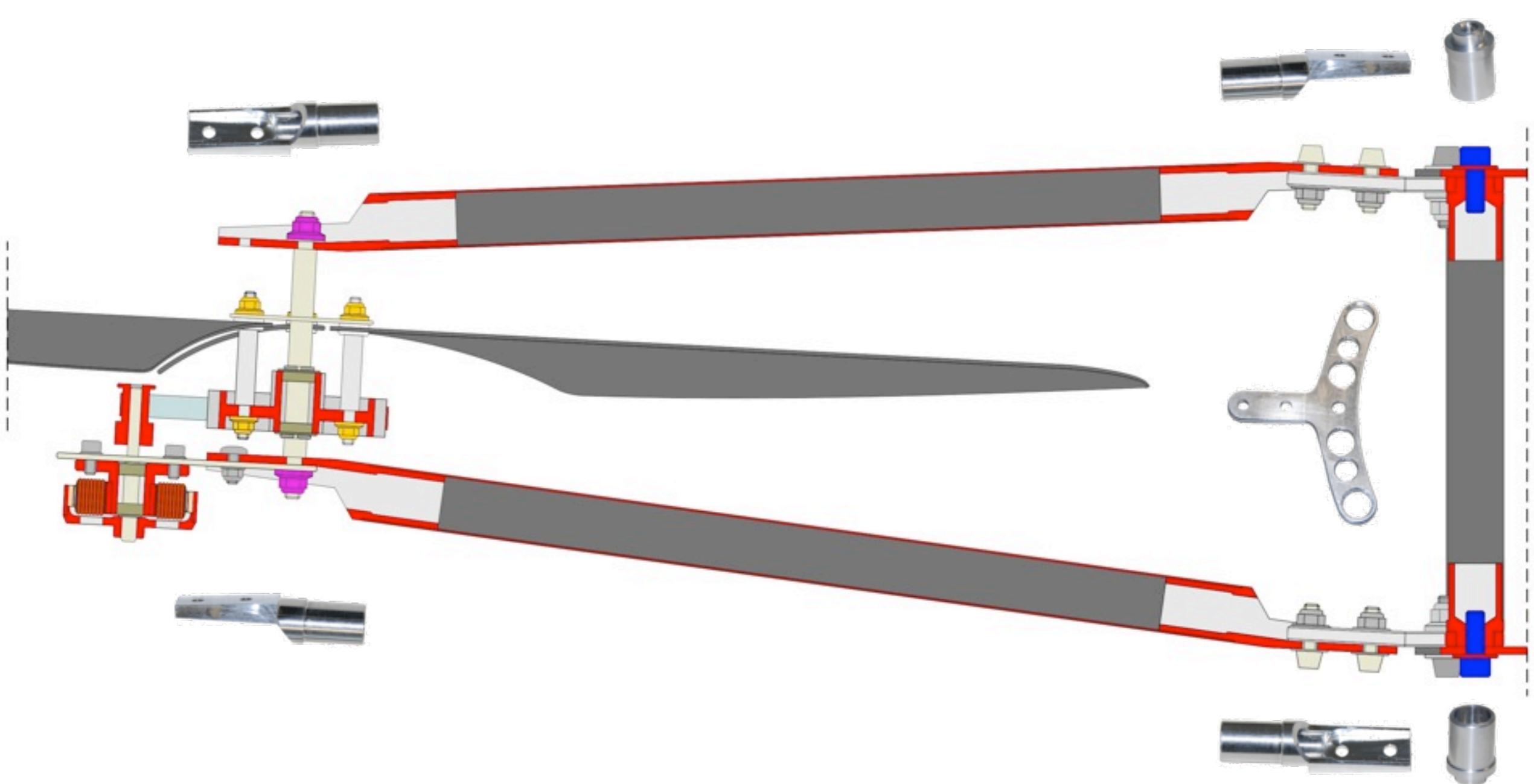
Minimal # of Different Parts



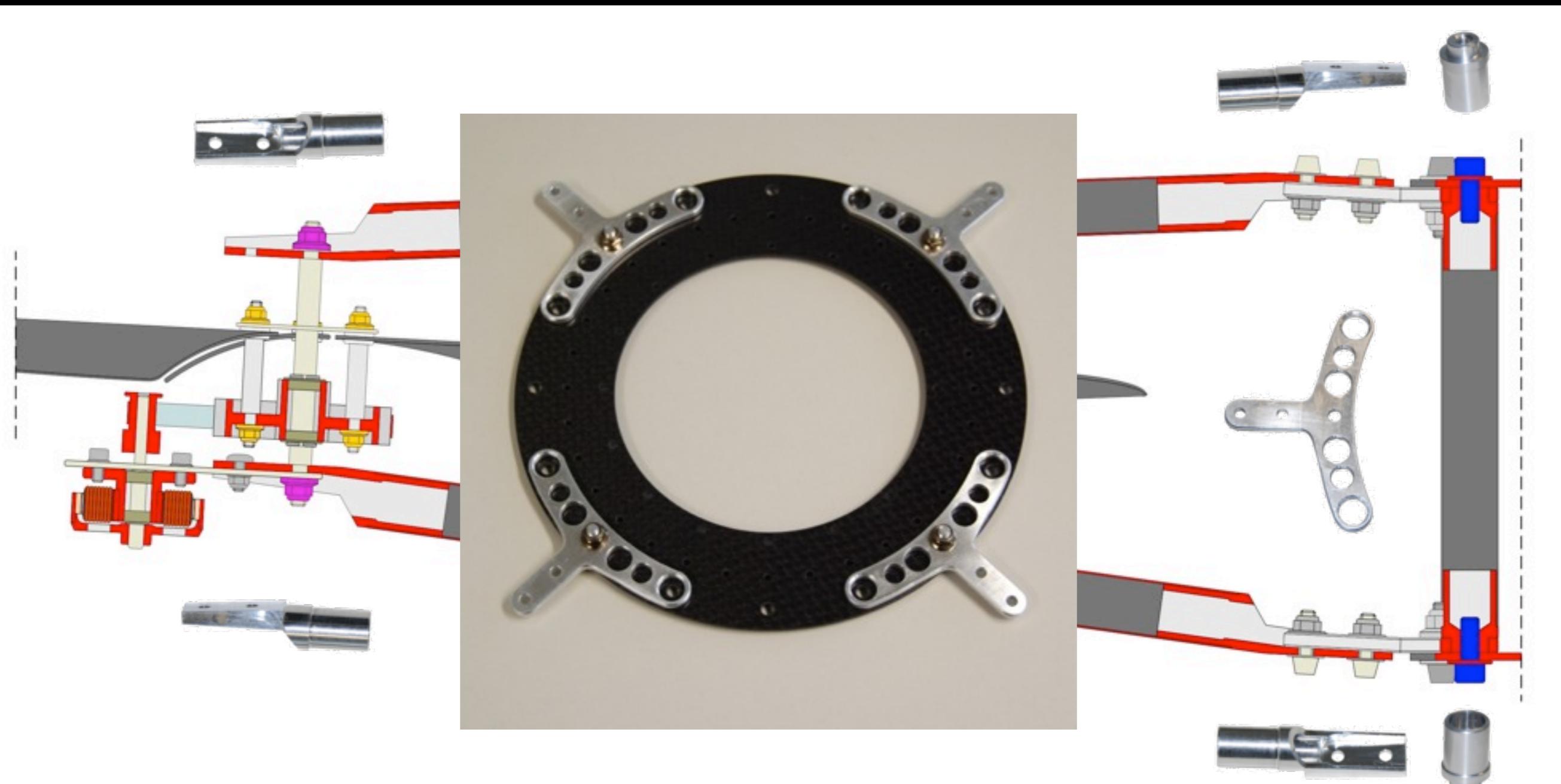
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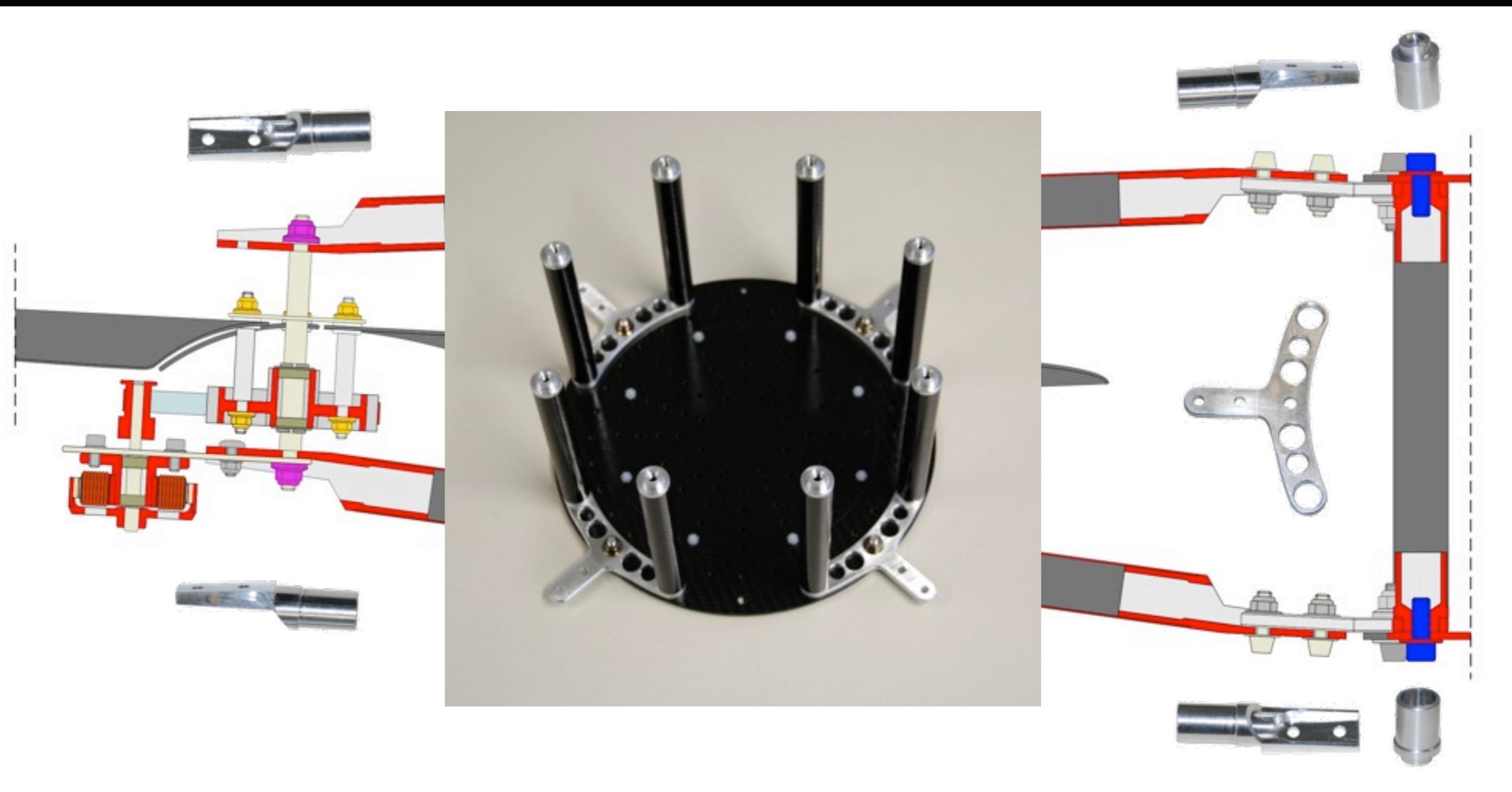
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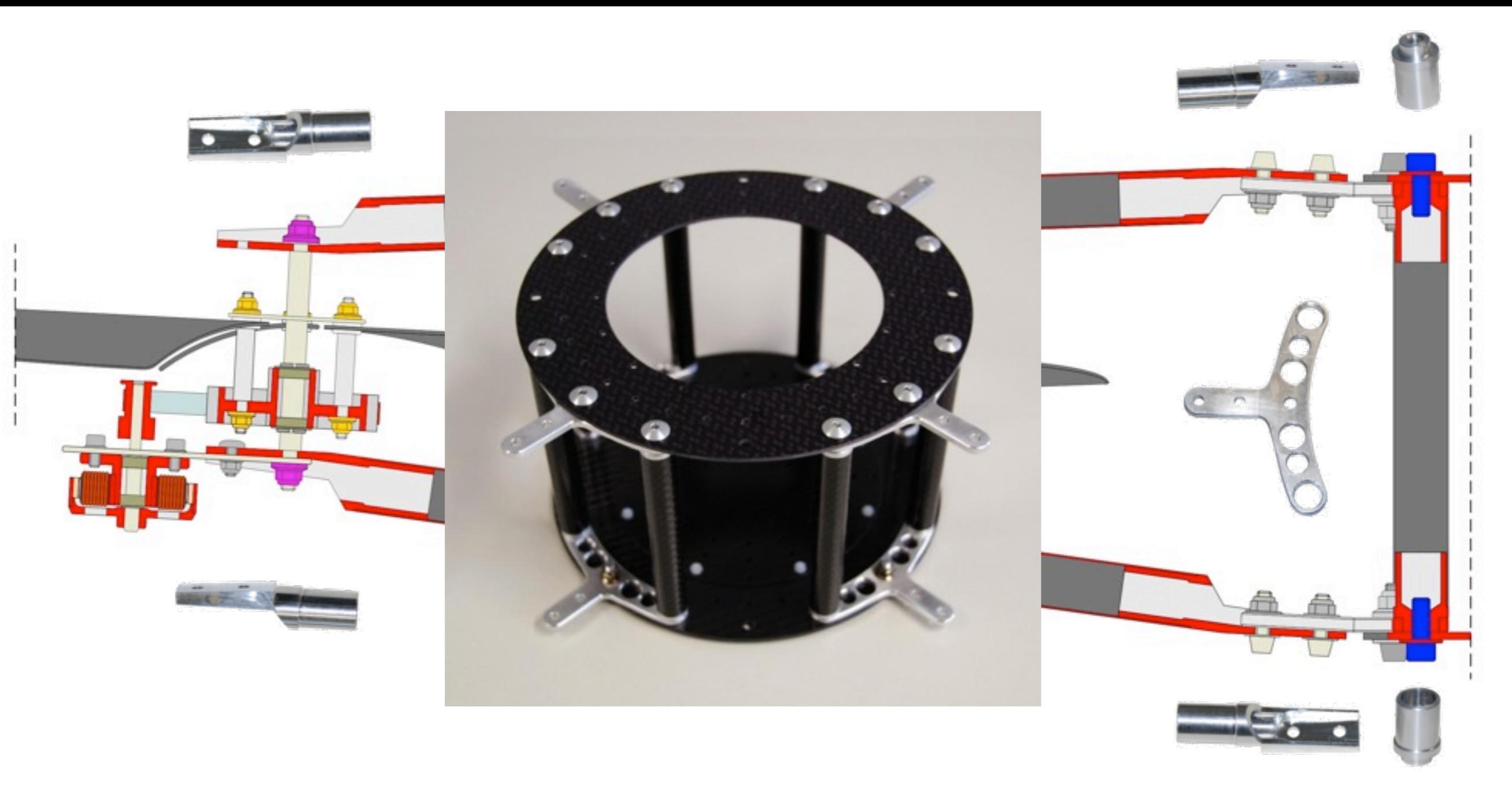
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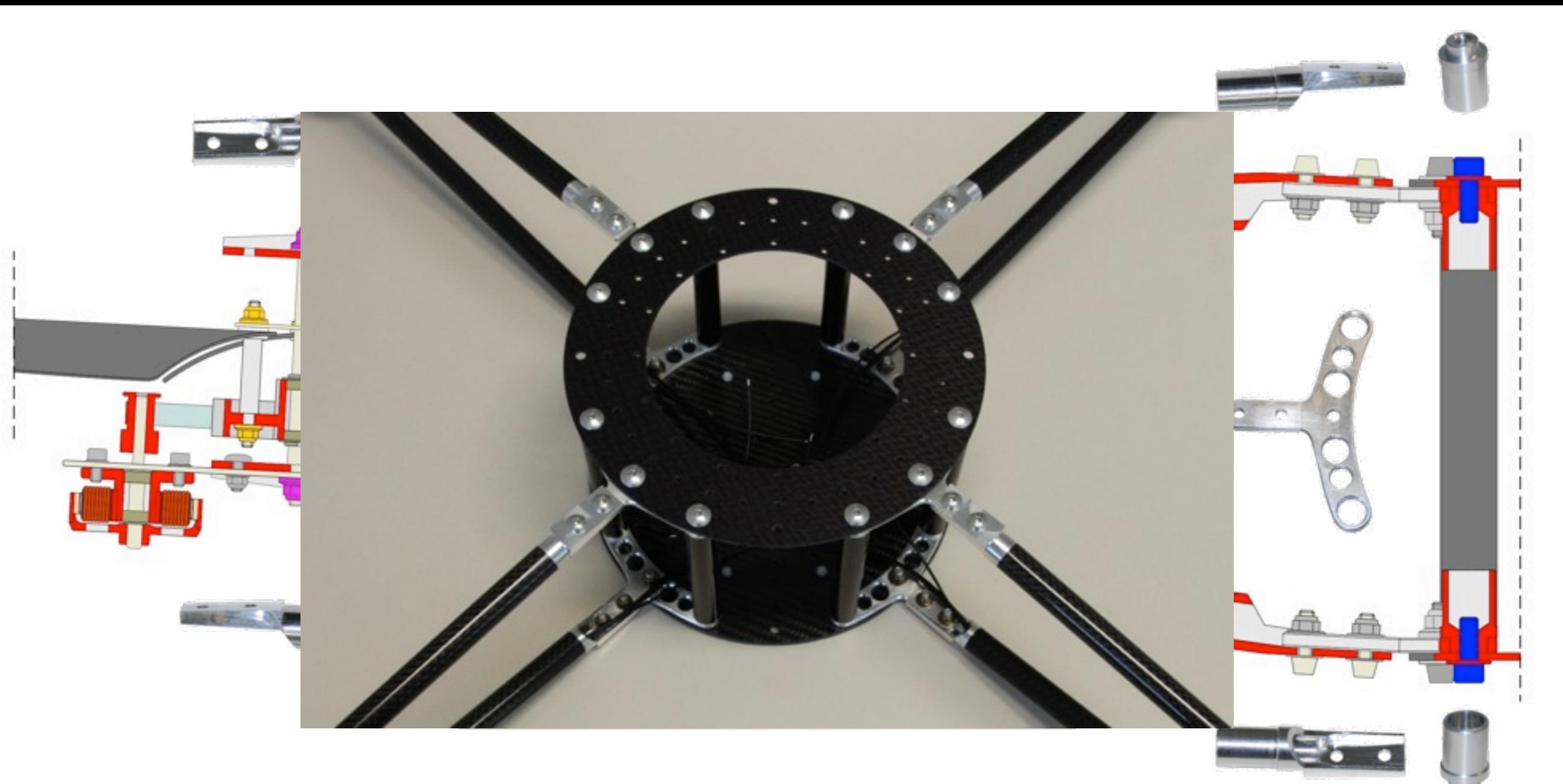
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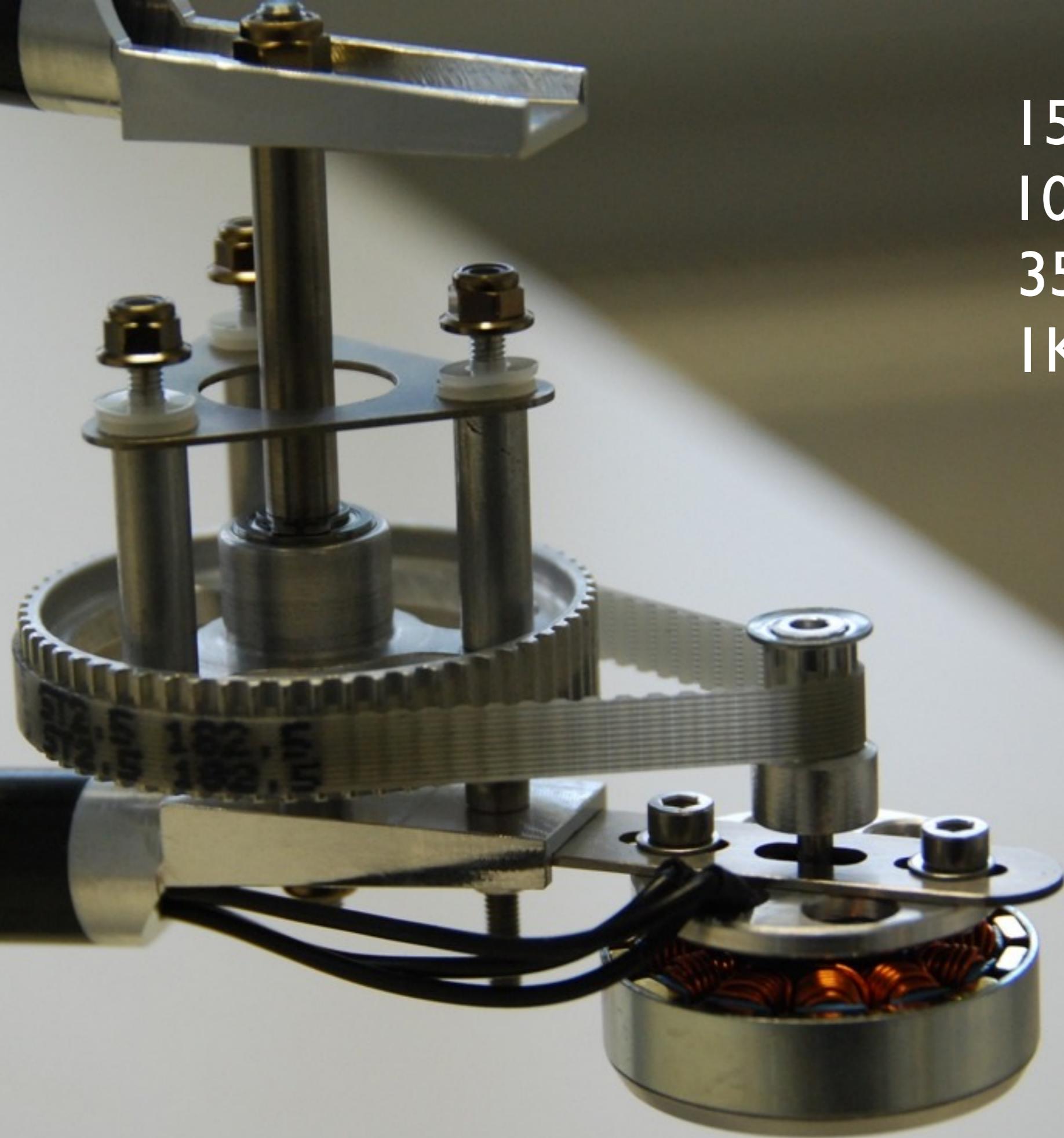
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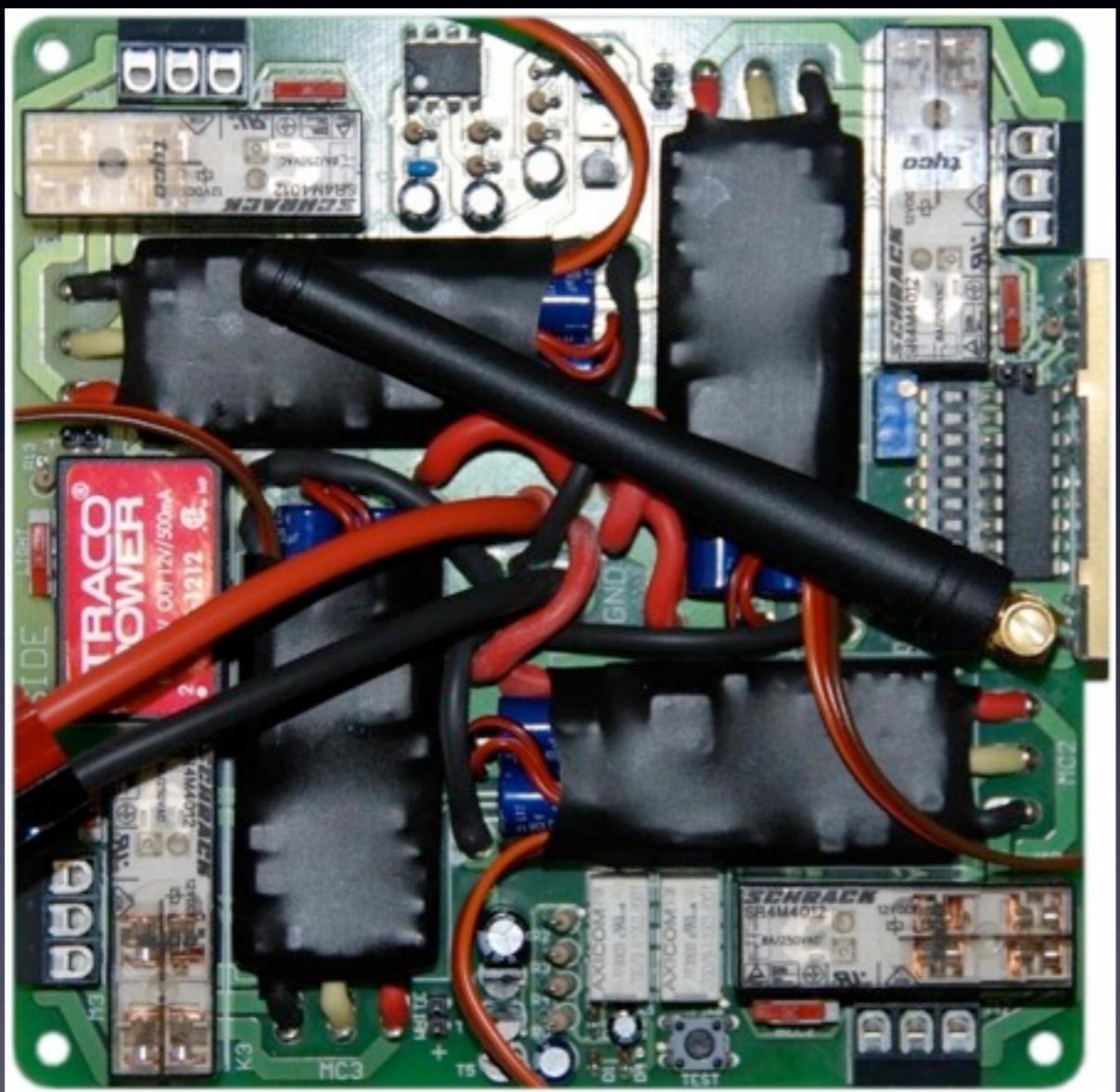


15V
10A
35g
1Kg





Custom Electronics

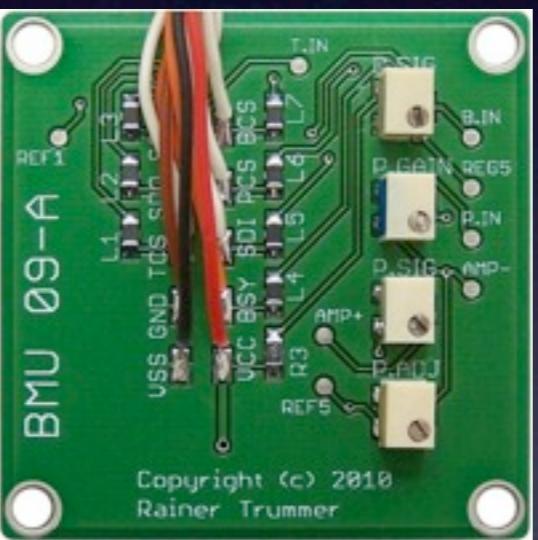
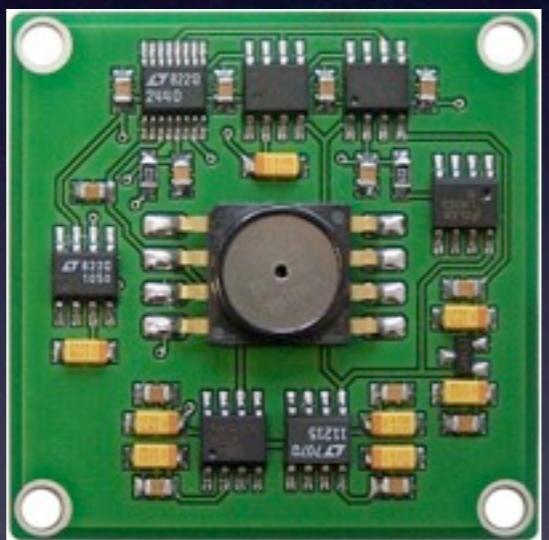


Power



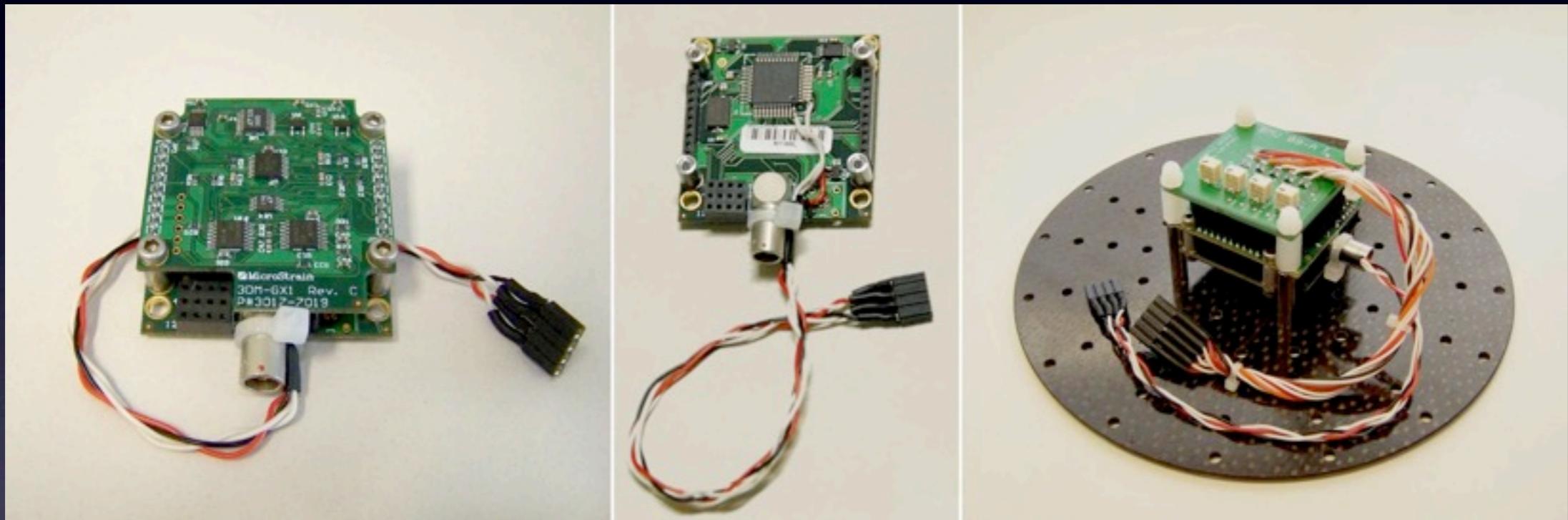
Remote

Custom Electronics



Barometer

Off-the-Shelf Stuff



Gyro

Off-the-Shelf Stuff



Ultrasonic

Off-the-Shelf Stuff

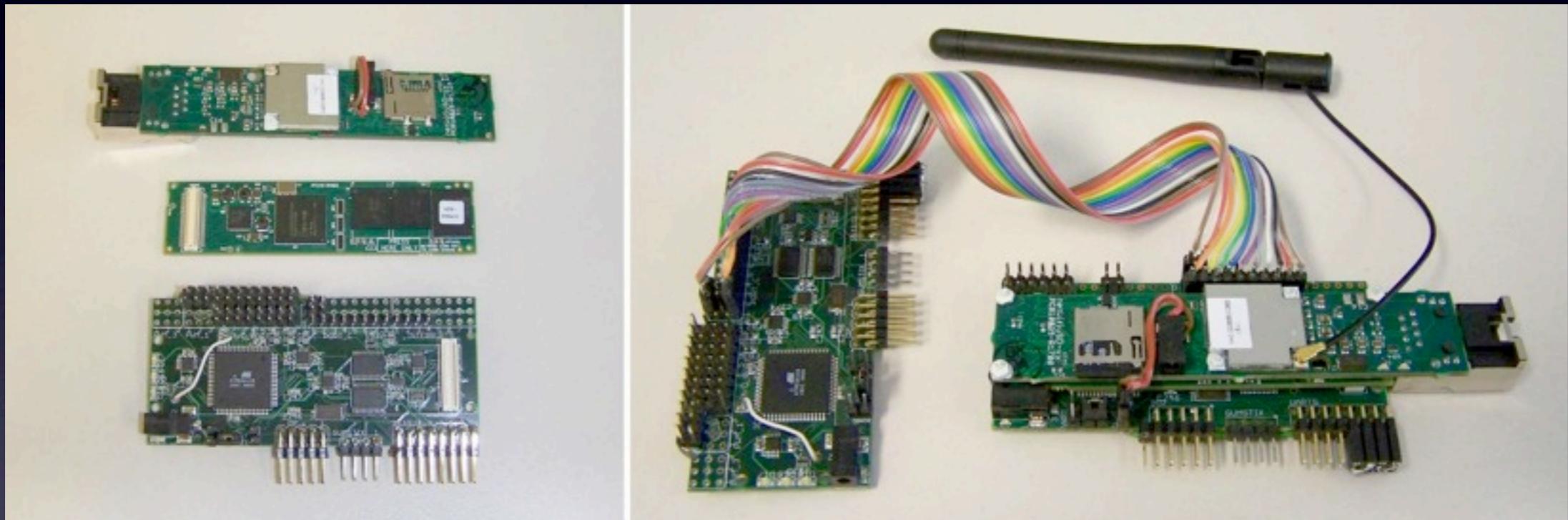


UWB RFID

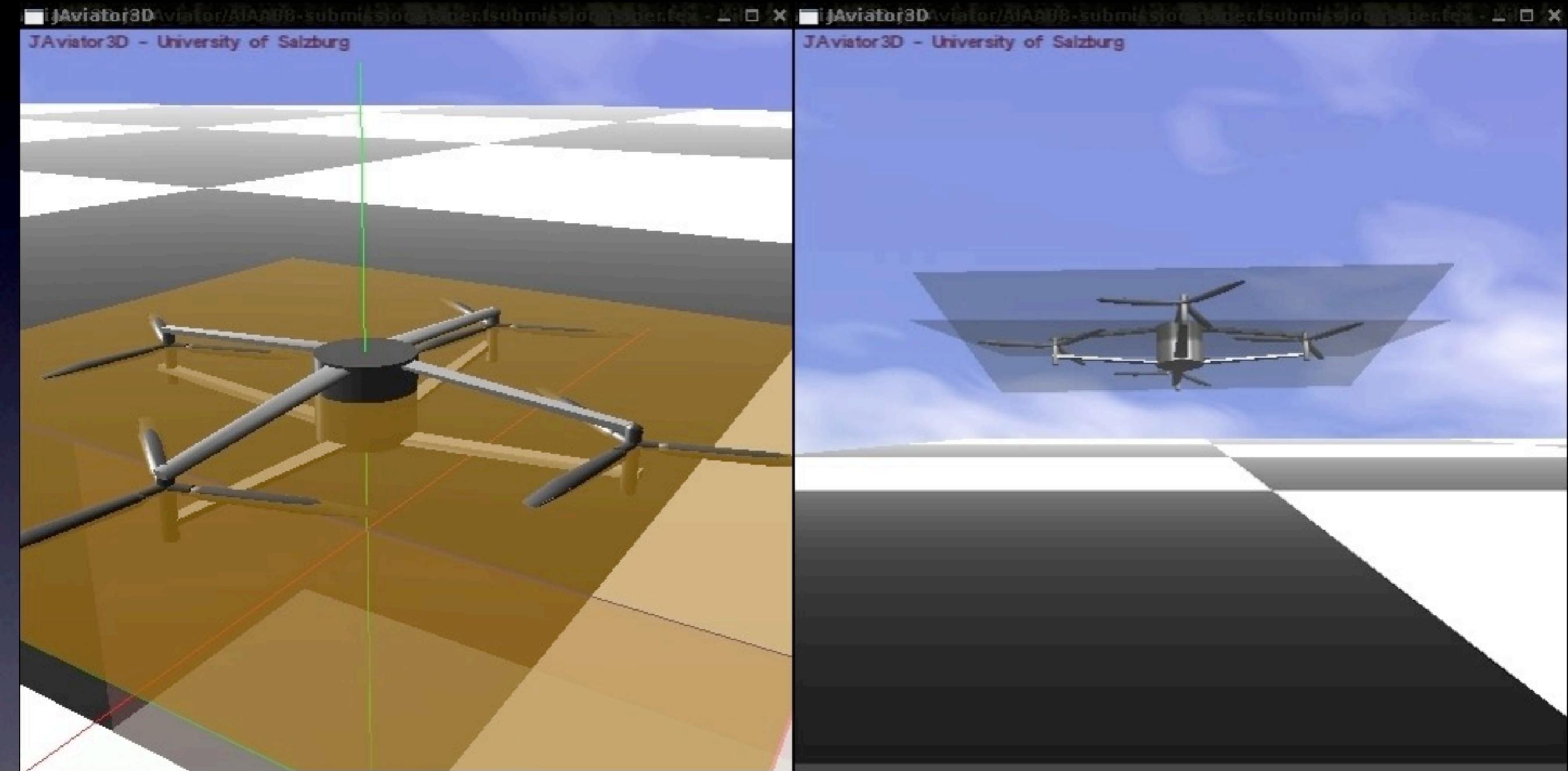


Laser

Off-the-Shelf Stuff

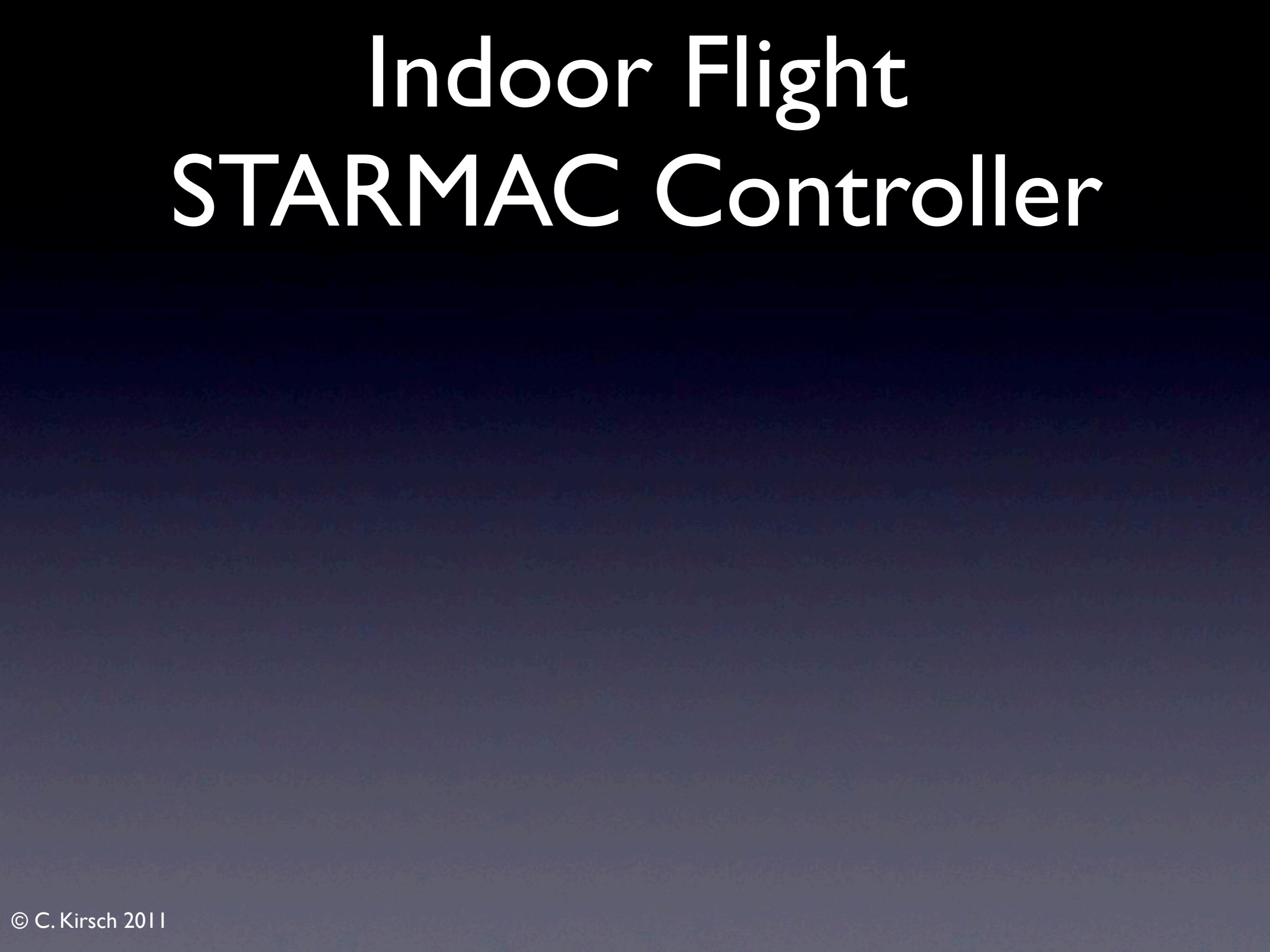


Gumstix

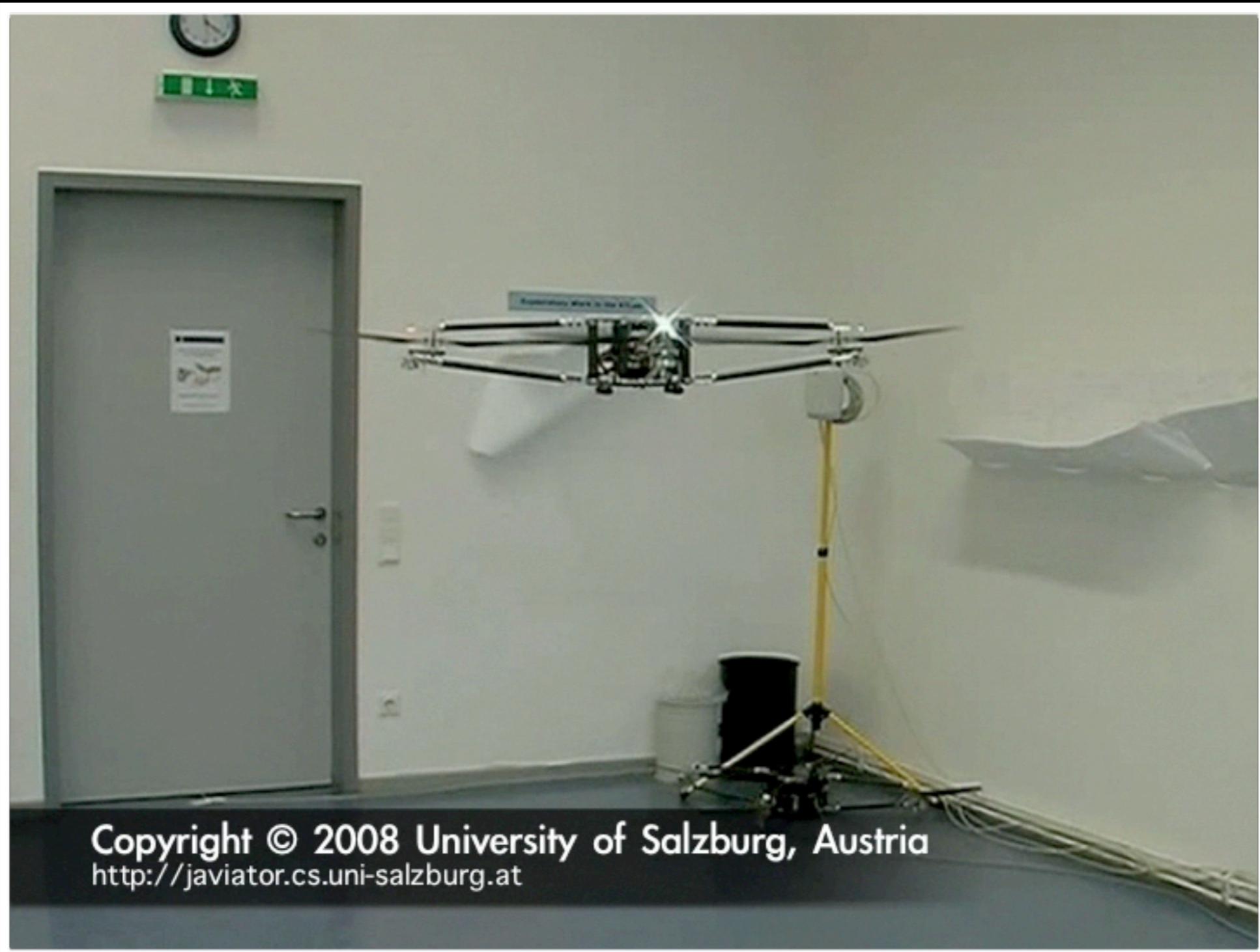




Indoor Flight STARMAC Controller



Indoor Flight STARMAC Controller



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<http://javiator.cs.uni-salzburg.at>

Outdoor Flight Salzburg Controller



Outdoor Flight Salzburg Controller



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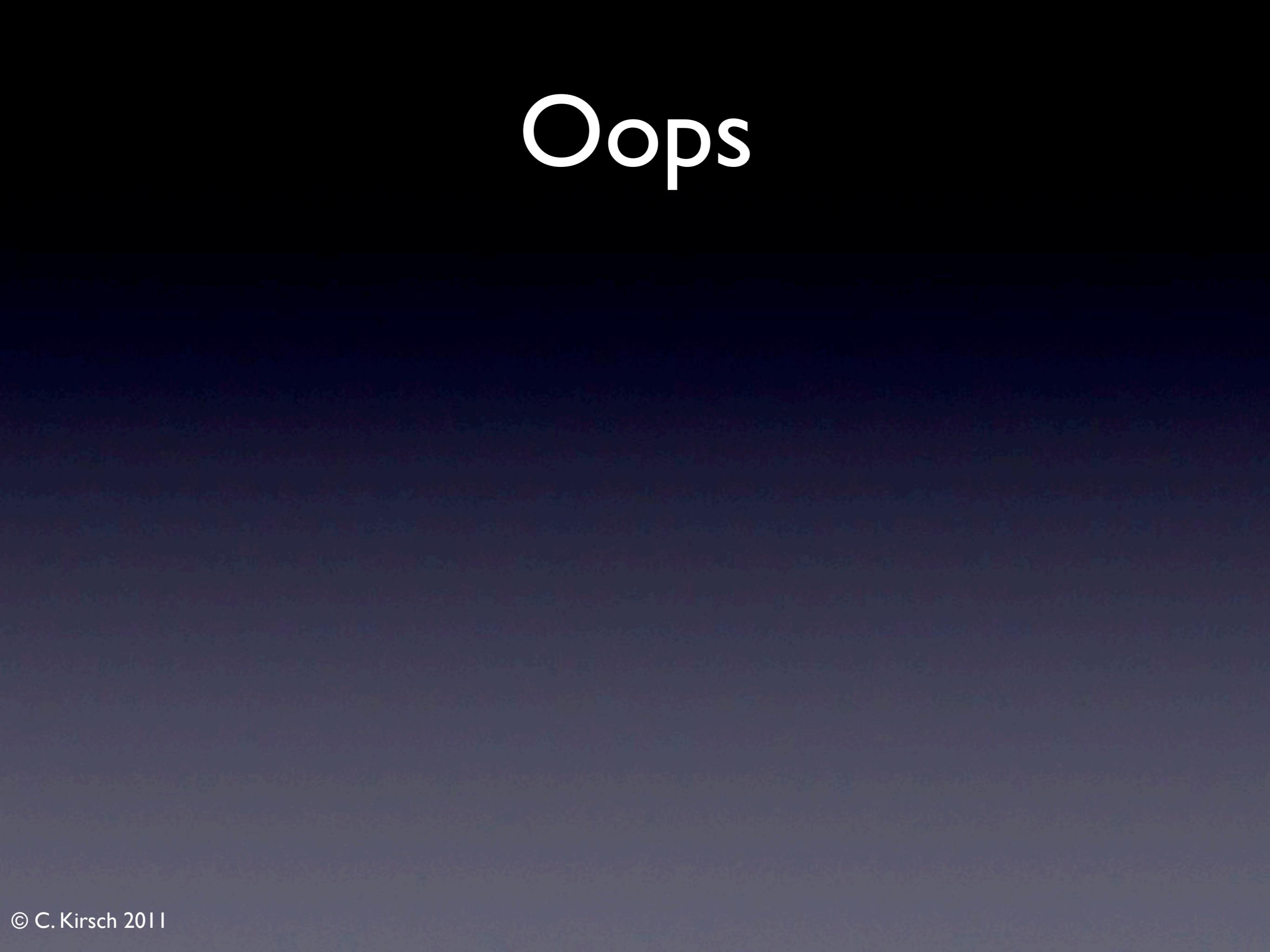
More Recent: Yawning



More Recent: Yawing



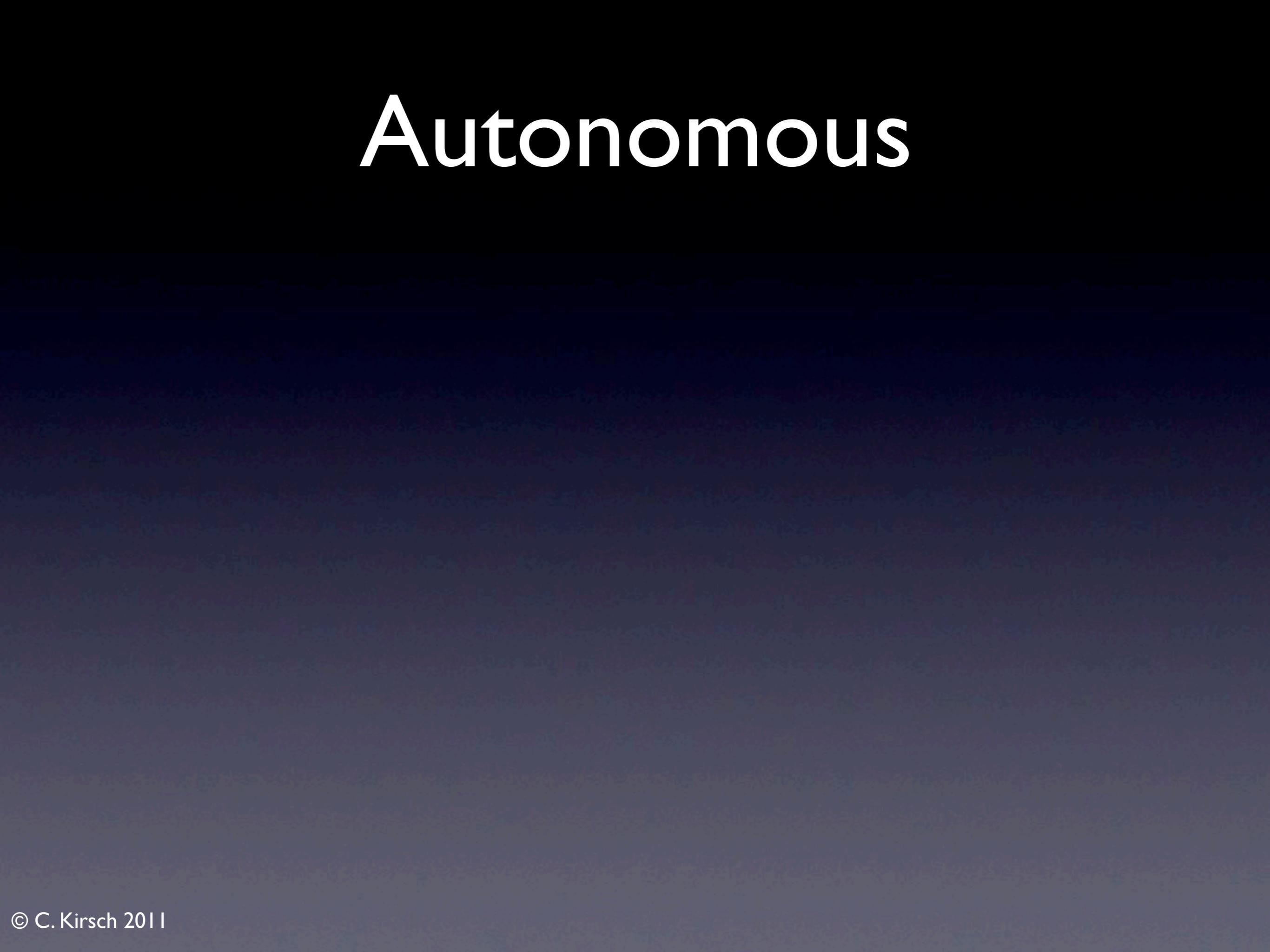
Oops



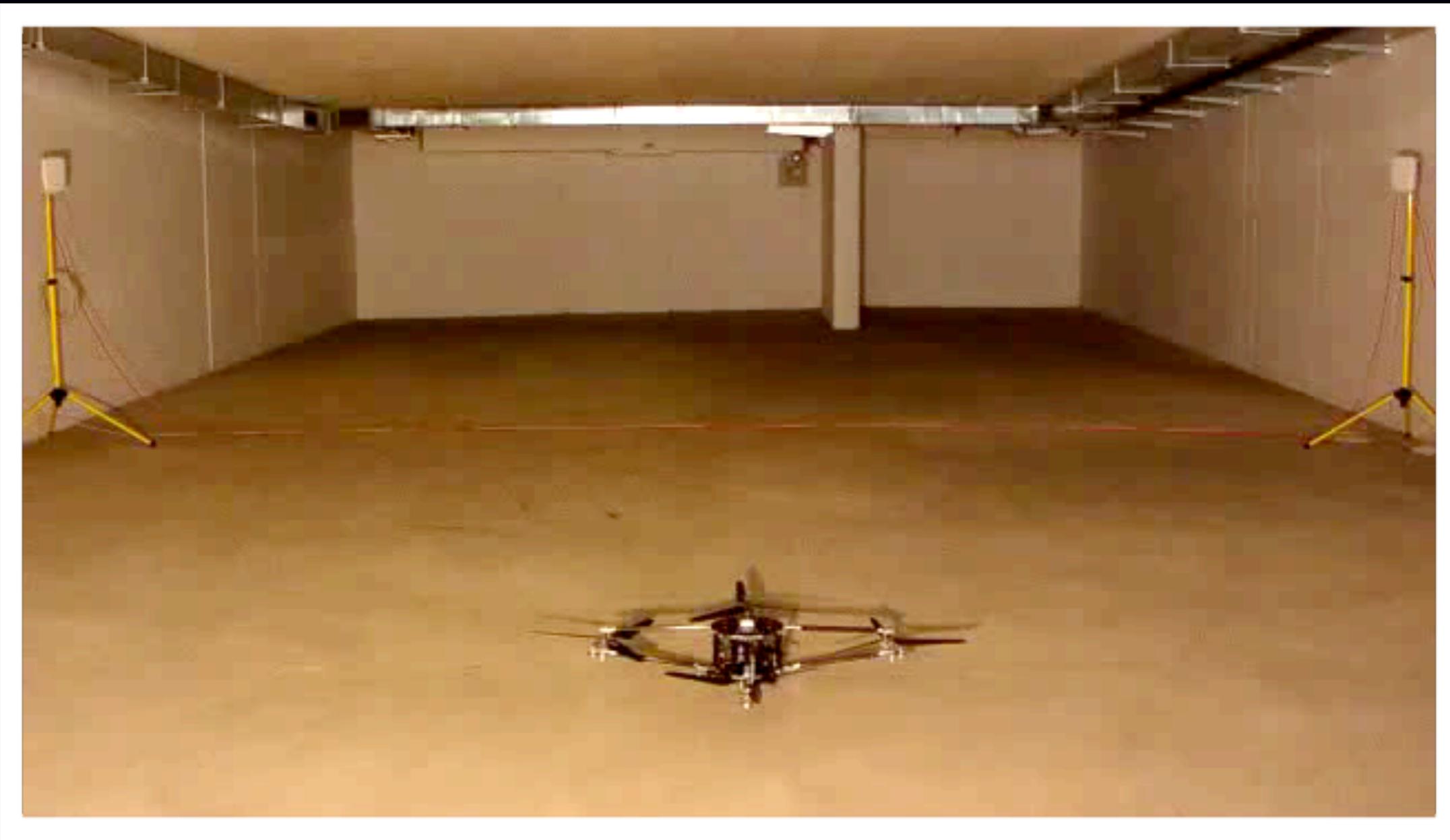
Oops



Autonomous



Autonomous



A Cyber-Physical Server



- IP address
- location

A Cyber-Physical Server



- IP address
- location
- capabilities

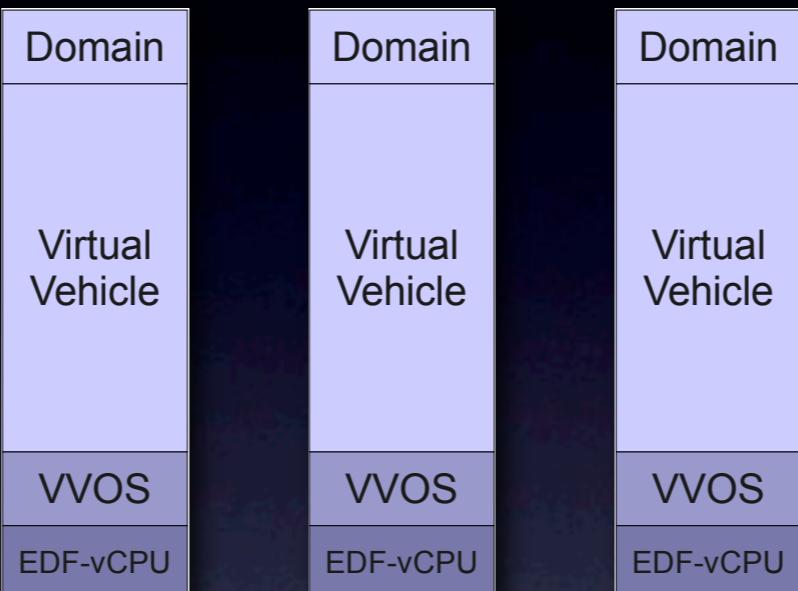
A Cyber-Physical Server



- IP address
- location
- capabilities
- motion

A Cyber-Physical Server

- IP address
- location
- capabilities
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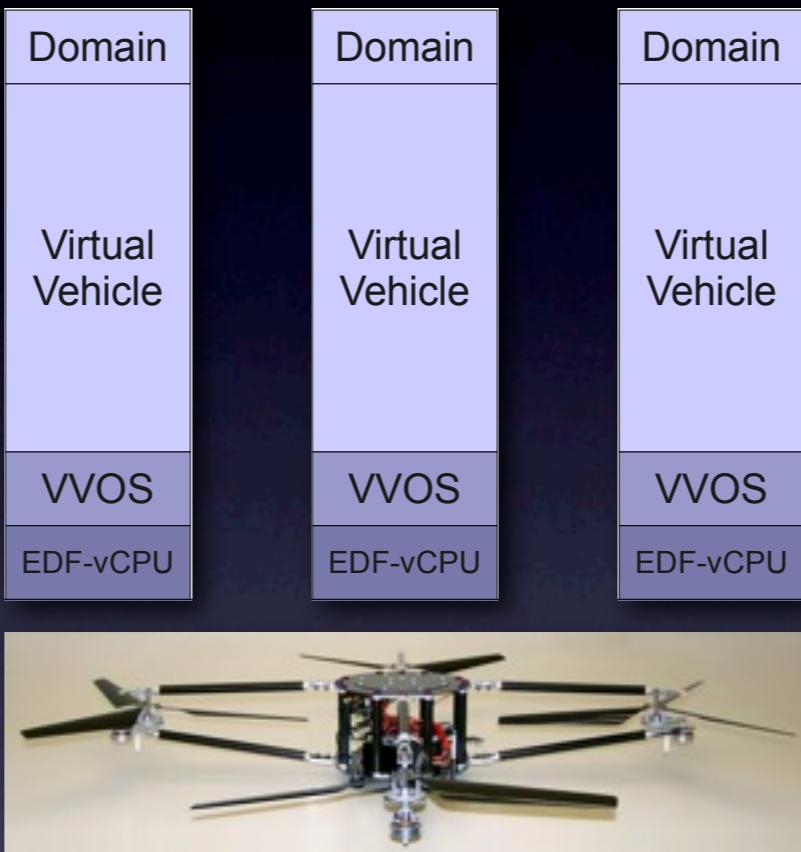
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A Cyber-Physical Server

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restricted



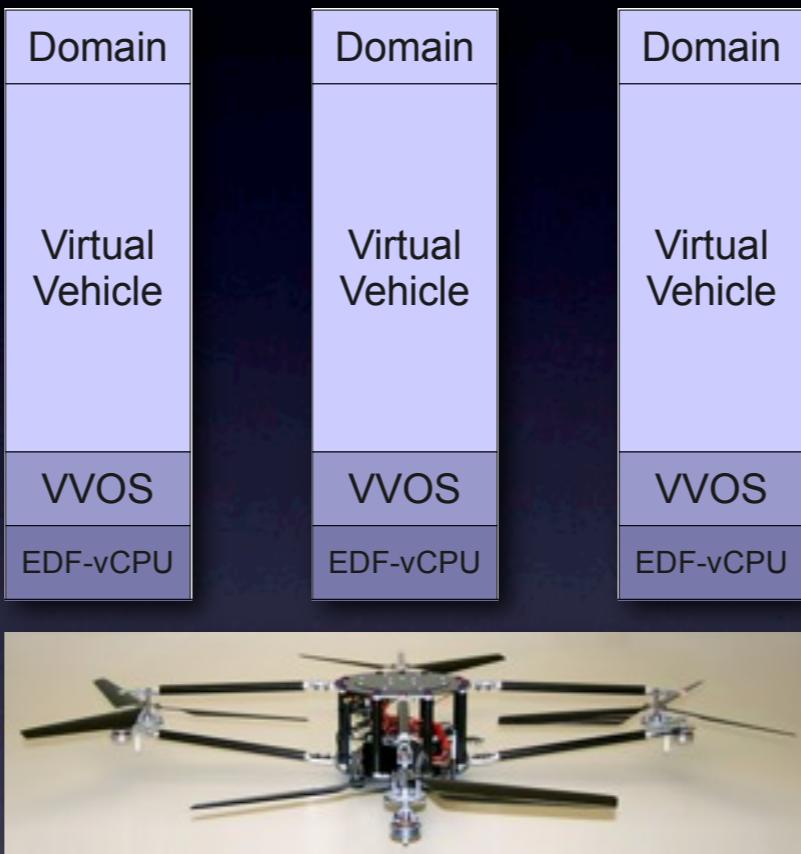
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A Cyber-Physical Server

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- location
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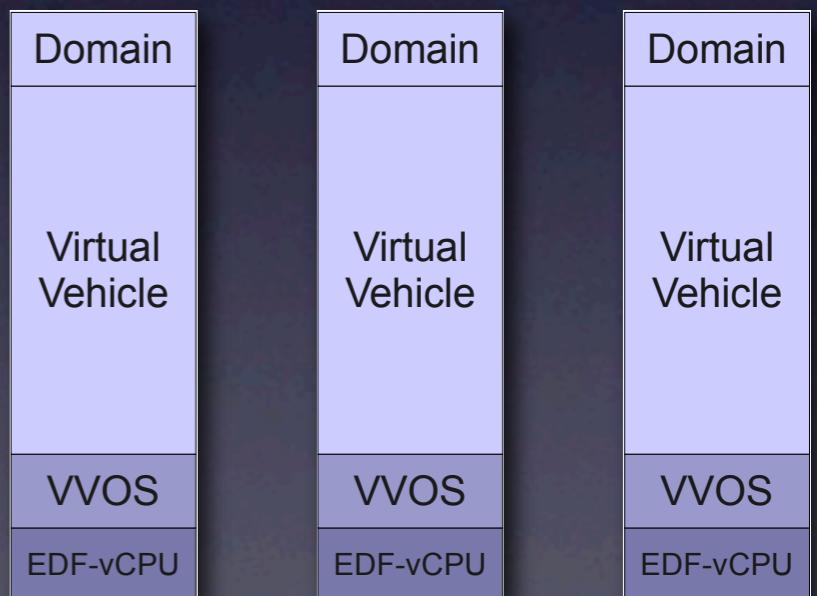
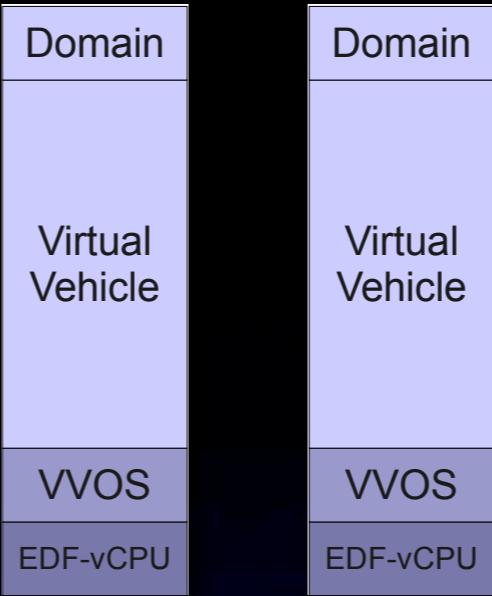
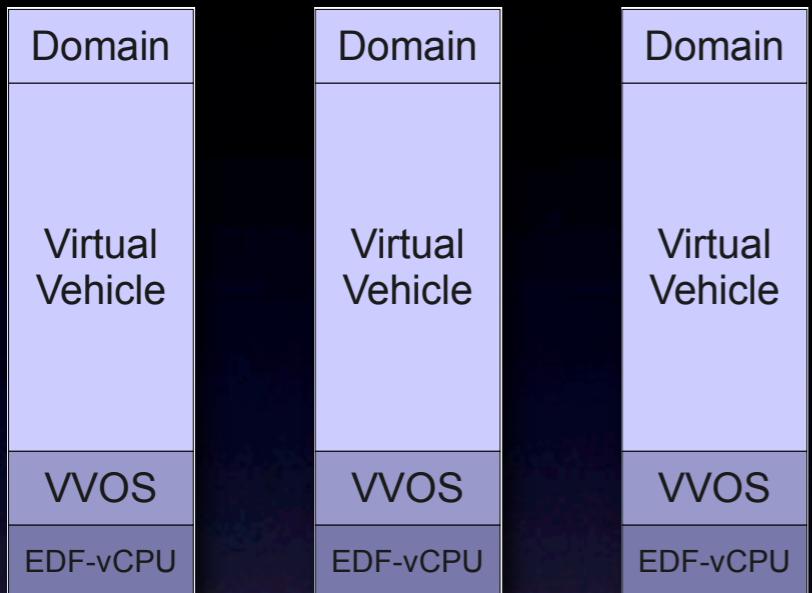
restricted



- IP address
- location
- capabilities
- motion

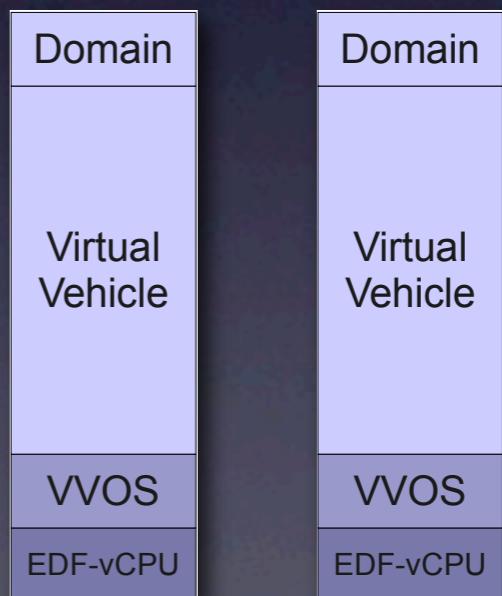
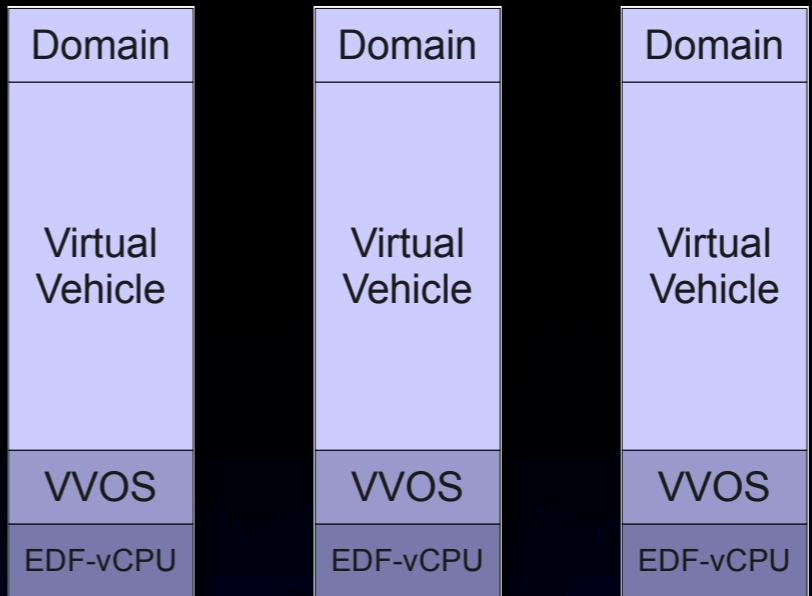
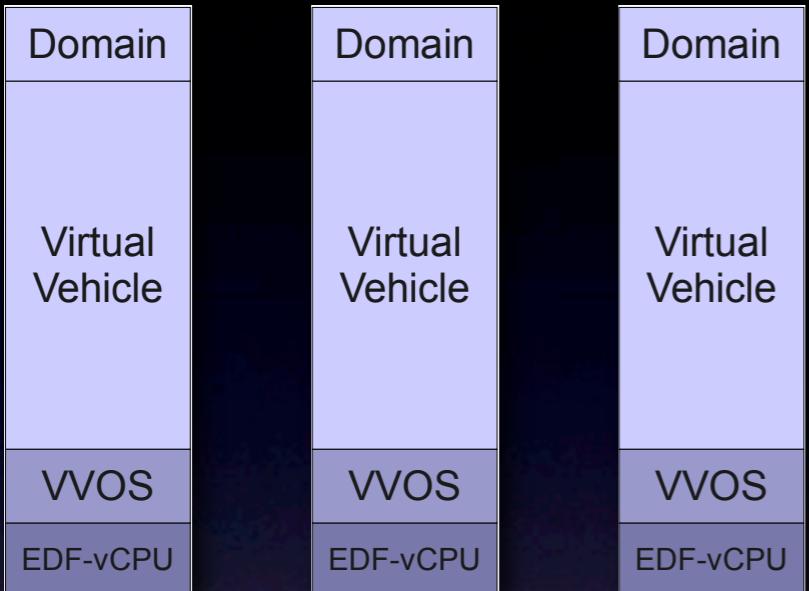
idealized

- IP address
- location
- capabilities
- motion



A Cyber-Physical Cloud [HotCloud 2010]

migration
=
flying



A Cyber-Physical Cloud [HotCloud 2010]

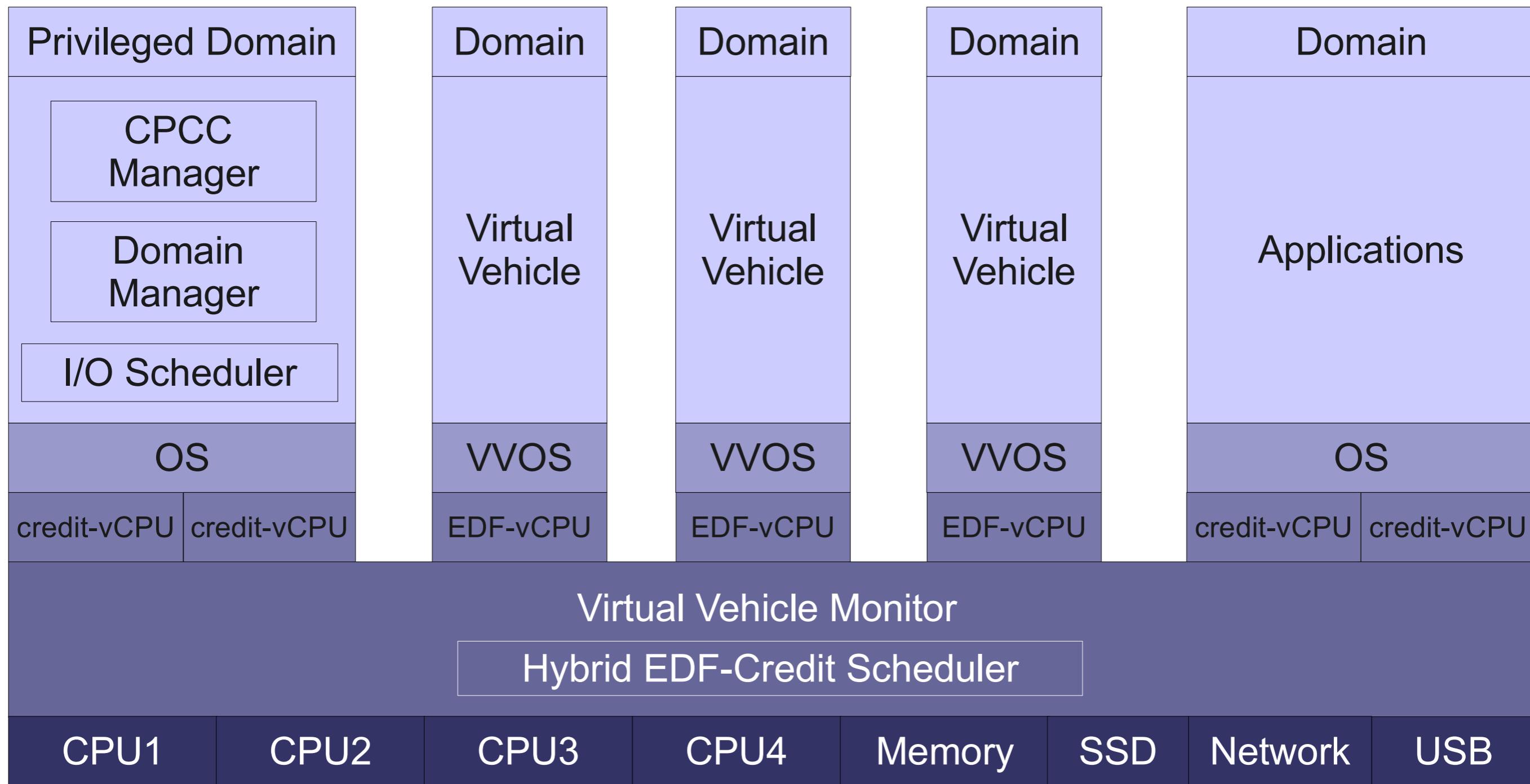
Goals

- Multi-provider (10s):
 - heterogeneous operations
- Multi-vehicle (100s):
 - heterogeneous systems
- Multi-task (1000s):
 - heterogeneous missions

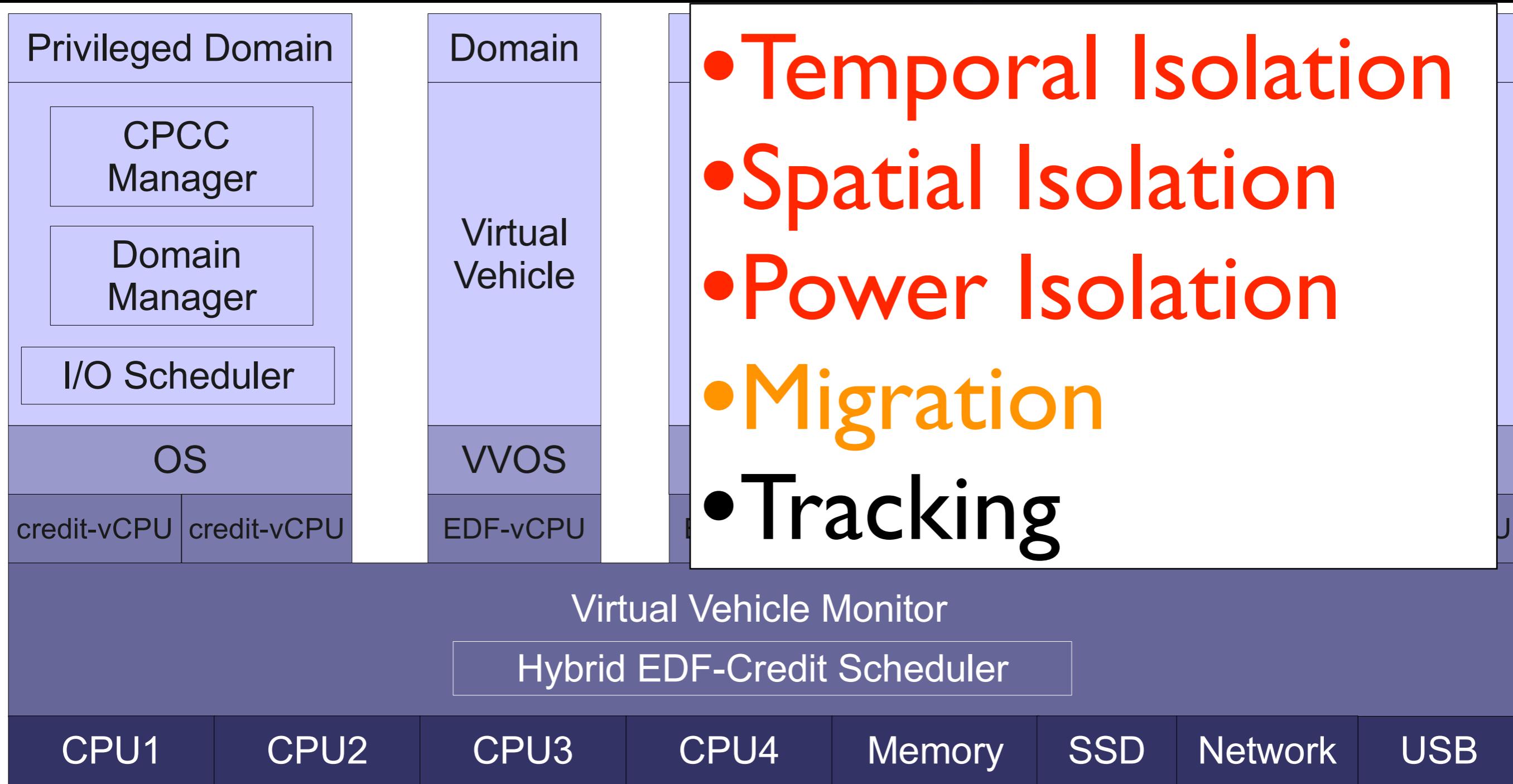
High-Level Challenges

- Virtualization **Infrastructure**
 - ▶ Salzburg
- Collaborative **Control**
 - ▶ Berkeley
- Programming **Language**
 - ▶ Berkeley, Salzburg

Virtualization Infrastructure



Virtualization Infrastructure



There is a
fundamental trade-off
between
quality and **cost**
of
time, space, power
isolation

Time

- **quality:** response time jitter
- **cost:** scheduling overhead

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Space

- **quality:** fragmentation jitter
- **cost:** management overhead

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Space

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- **cost:** management overhead

Power

- **quality:** power consumption jitter
- **cost:** total power consumption

Time

Variable-Bandwidth Servers (VBS)
[SIES09]

VBS Overhead Accounting
[RTAS10]

Space

Compact-fit
[USENIX ATC08]

Short-term Memory
[Submitted II]

Power

Power-aware VBS
[EMSOFT10]

The Power of Isolation
[Submitted II]

Time

- **per-process** lower/upper bounds
on response times [SIES09]

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Space

Power

Power-aware VBS

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The Power of Isolation

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- save power while maintaining response times [EMSOFT10]

Space

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The Power of Isolation
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- refresh needed rather than deallocate not-needed objects [Submitted II]
- save power while maintaining response times [EMSOFT10]
- per-process lower/upper bounds on power consumption [Submitted II]

Space

Power

The trade-off
between
isolation **quality** and **cost**
extends to
scalability
on **multicore** systems

Multicore

- many concurrent data structures **do not scale**,
e.g. a concurrent FIFO queue for scheduling

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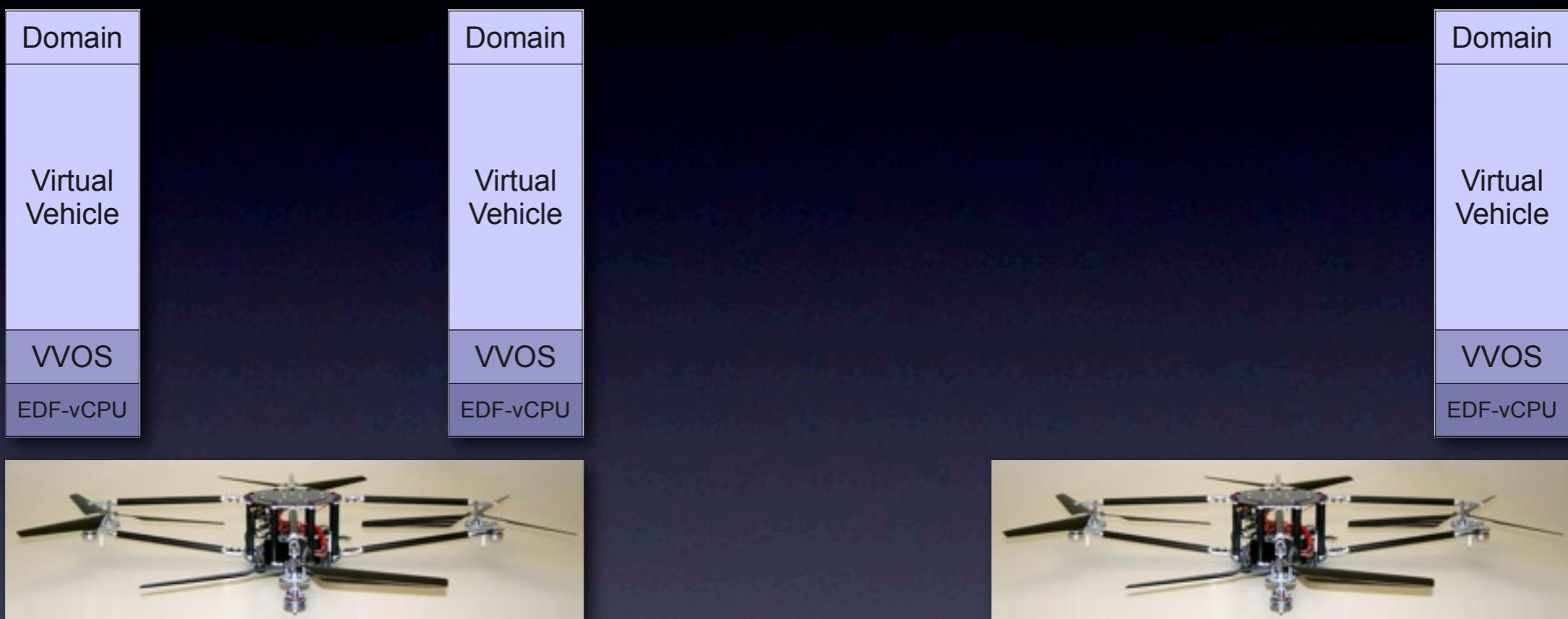
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Non-linearizable Computing Breaks the Scalability Barrier [Submitted ||]

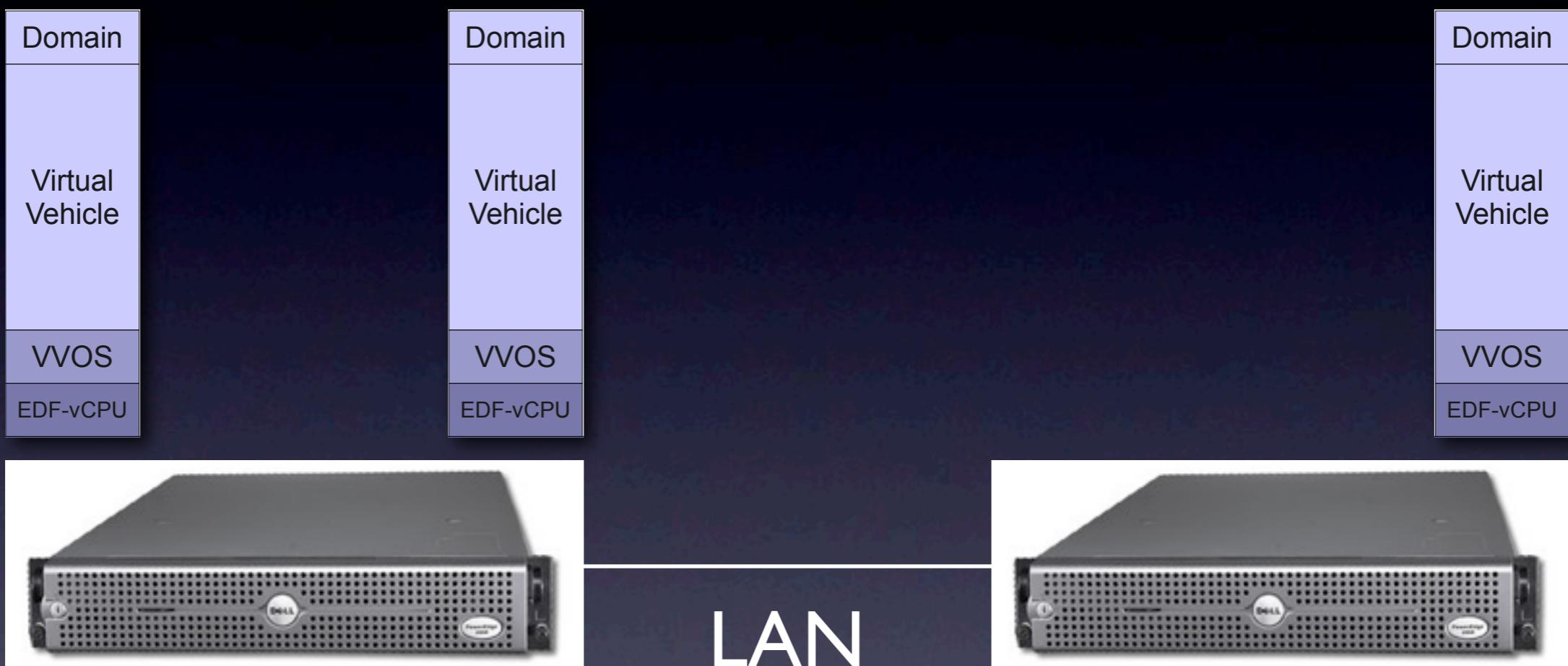
Virtual Vehicle Demo

by Florian Landolt and Andreas Rottmann



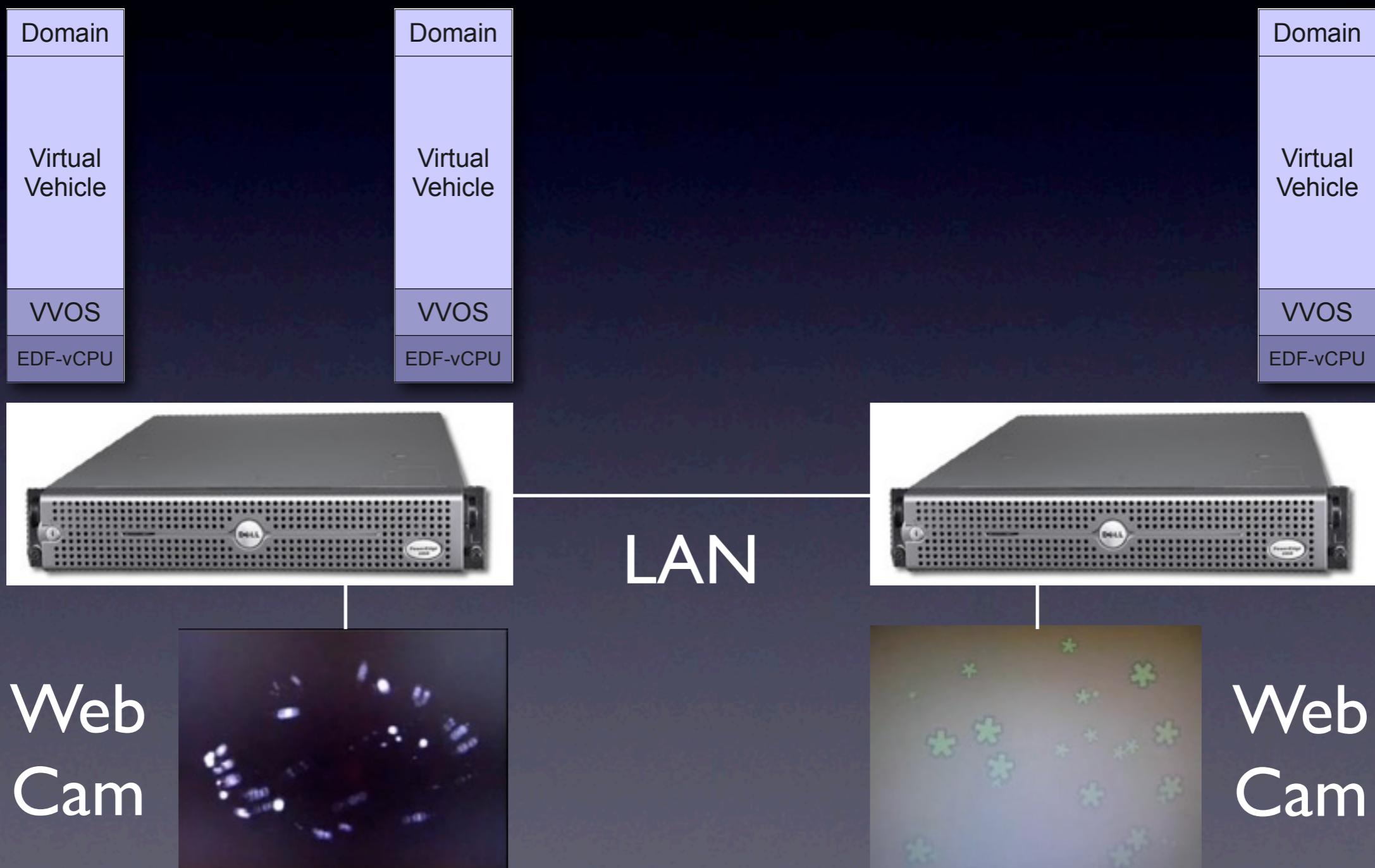
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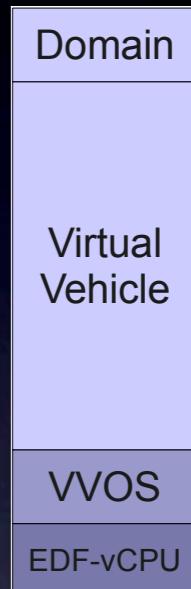
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Laptop



LAN

Web
Cam



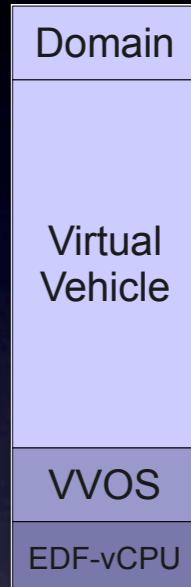
Web
Cam



Laptop



Multicast



LAN



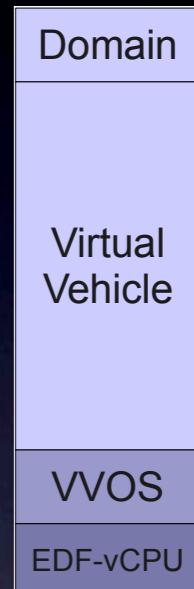
Web
Cam



Web
Cam



Laptop



Migration



LAN

Web
Cam



Web
Cam

Laptop



Web Cam



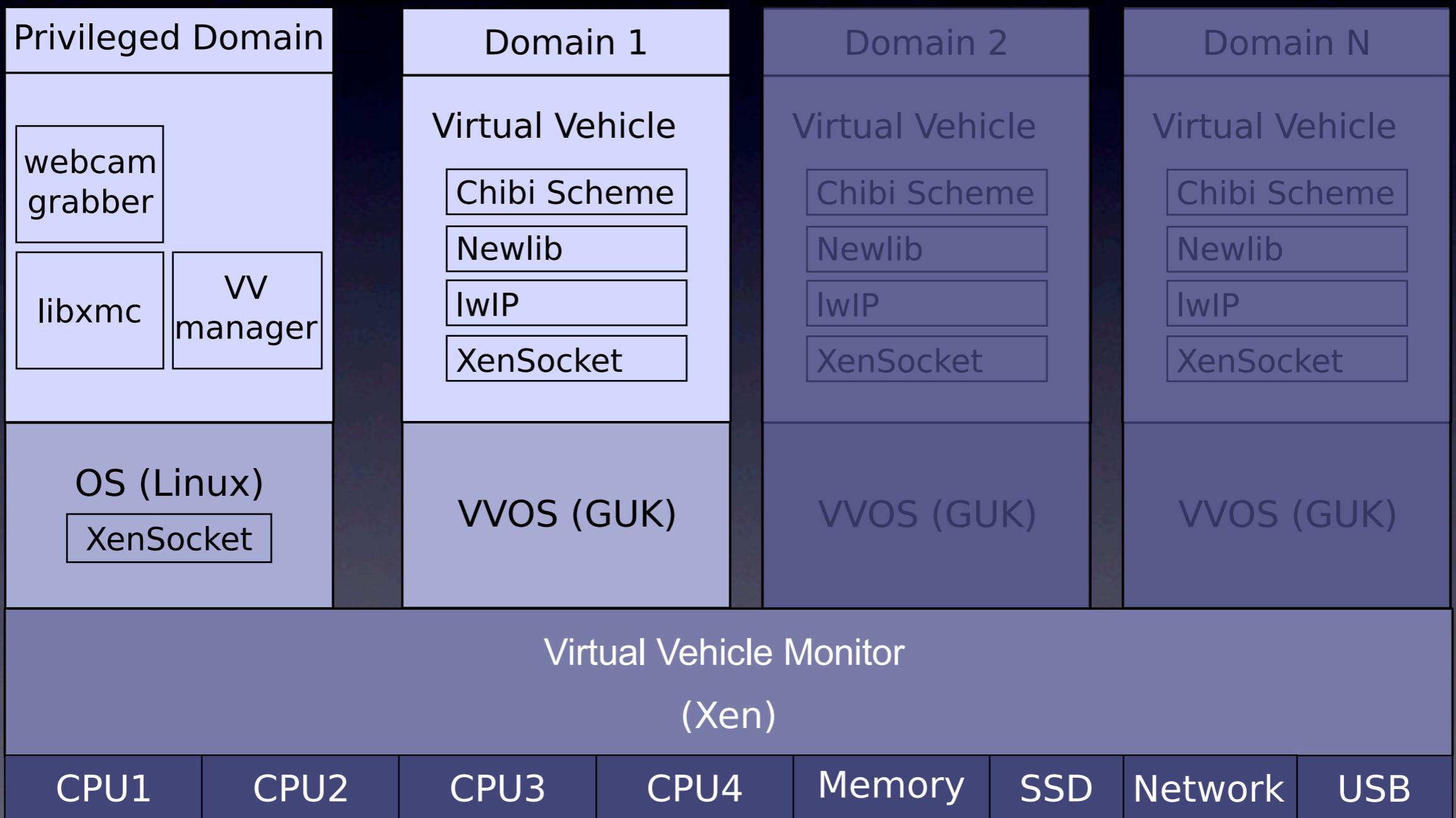
LAN



Web Cam

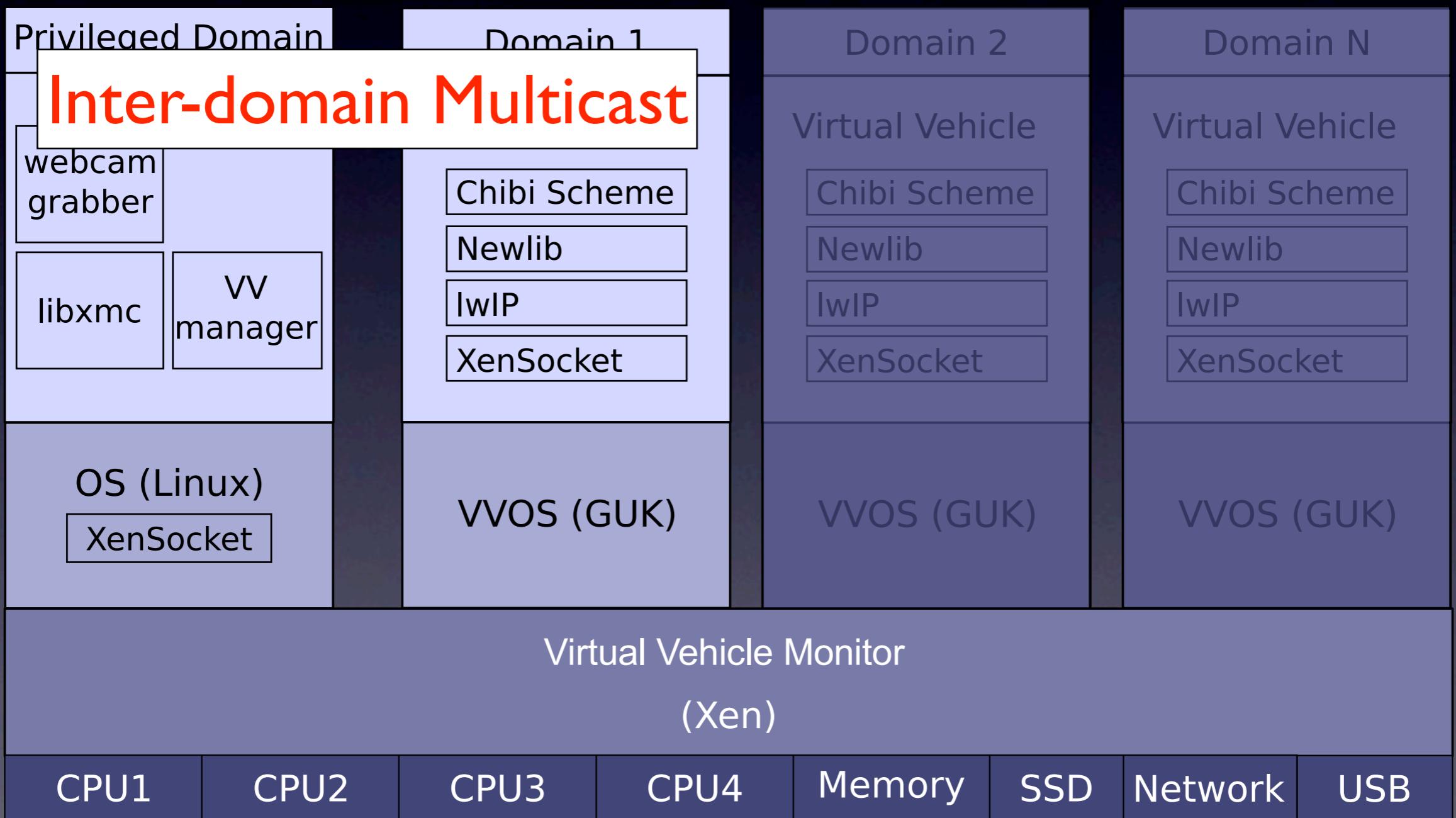
Virtual Vehicle Monitor

(Xen, XenSockets, GUK, lwIP, Newlib, Chibi Scheme)



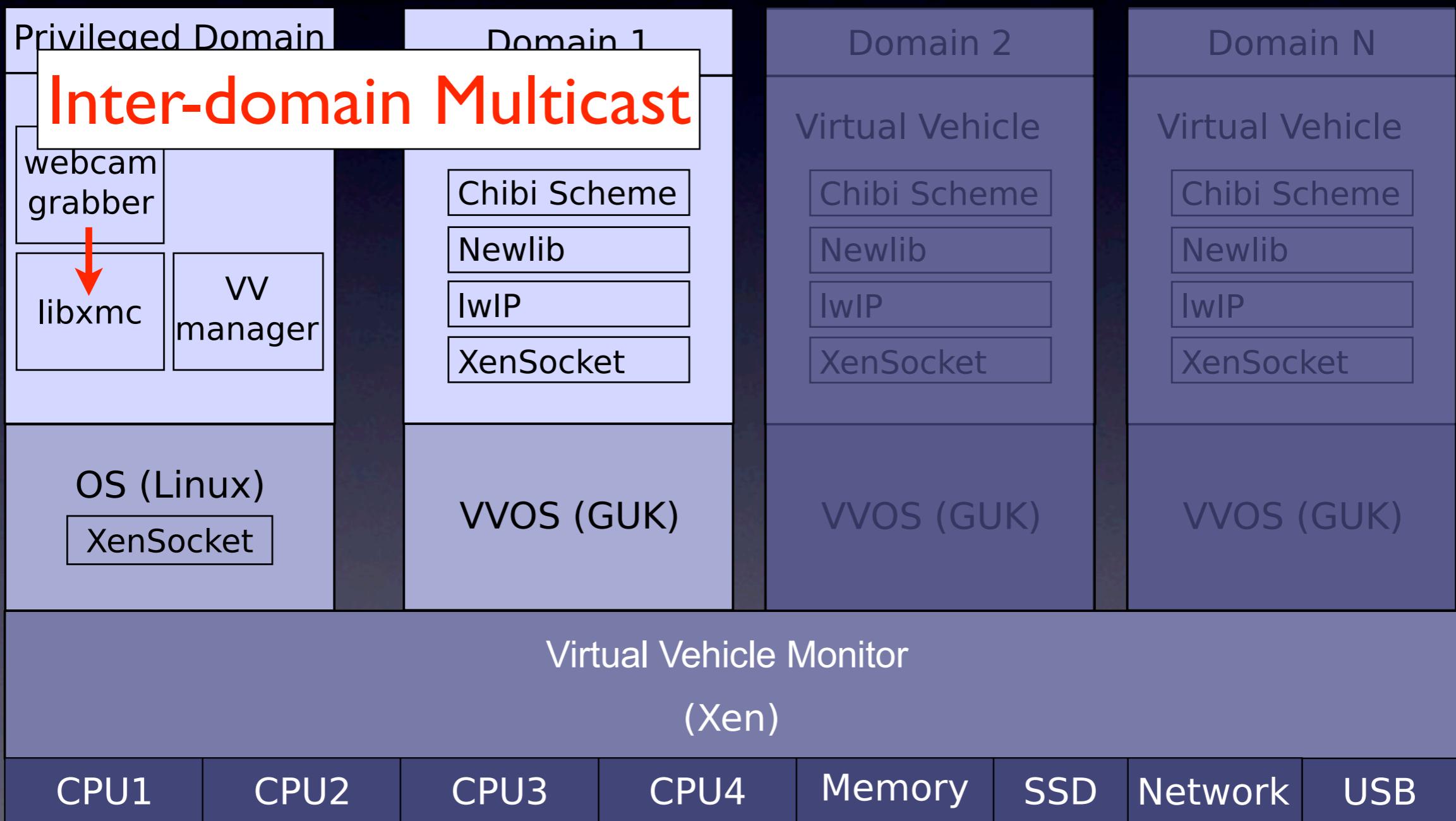
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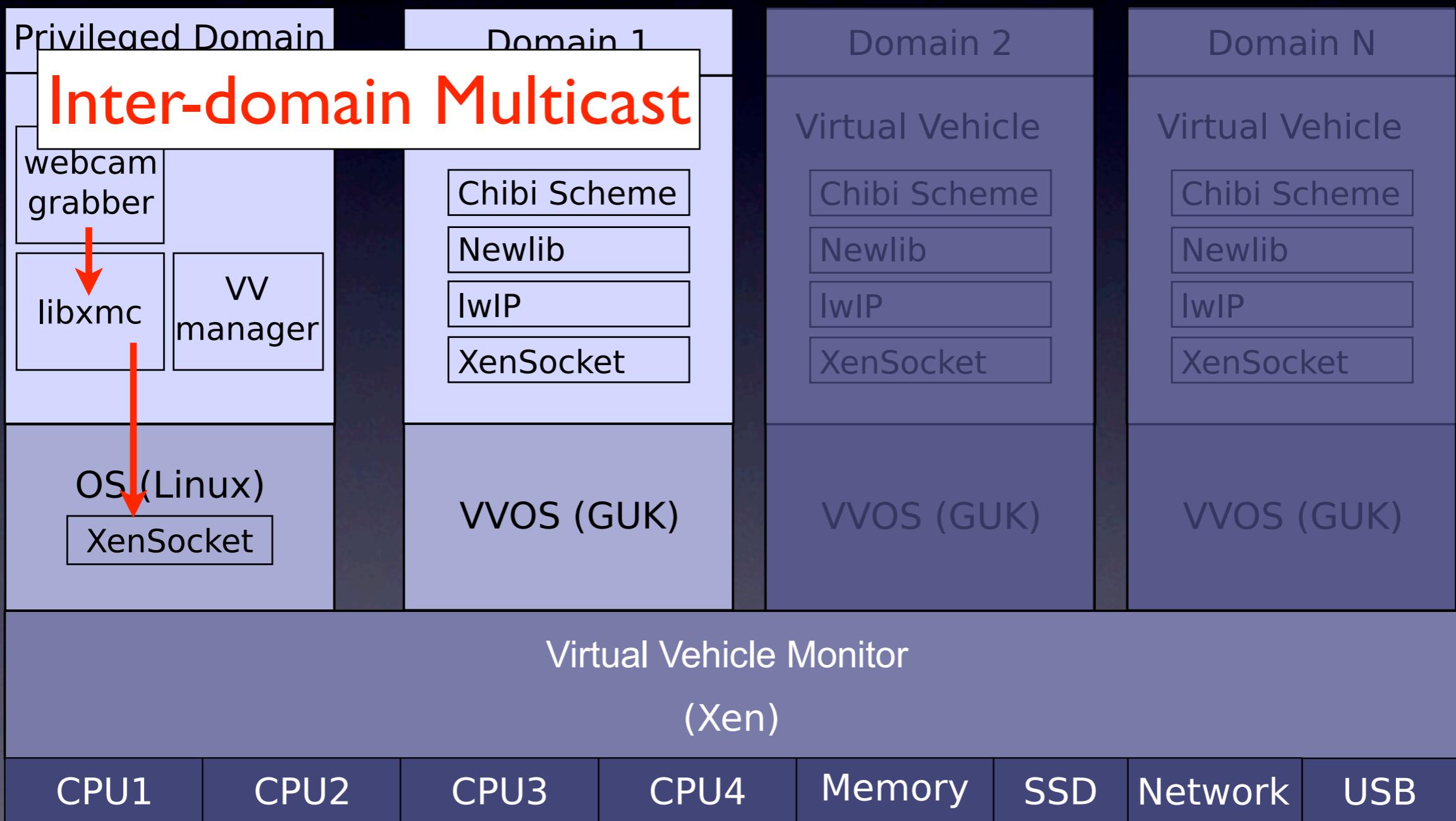
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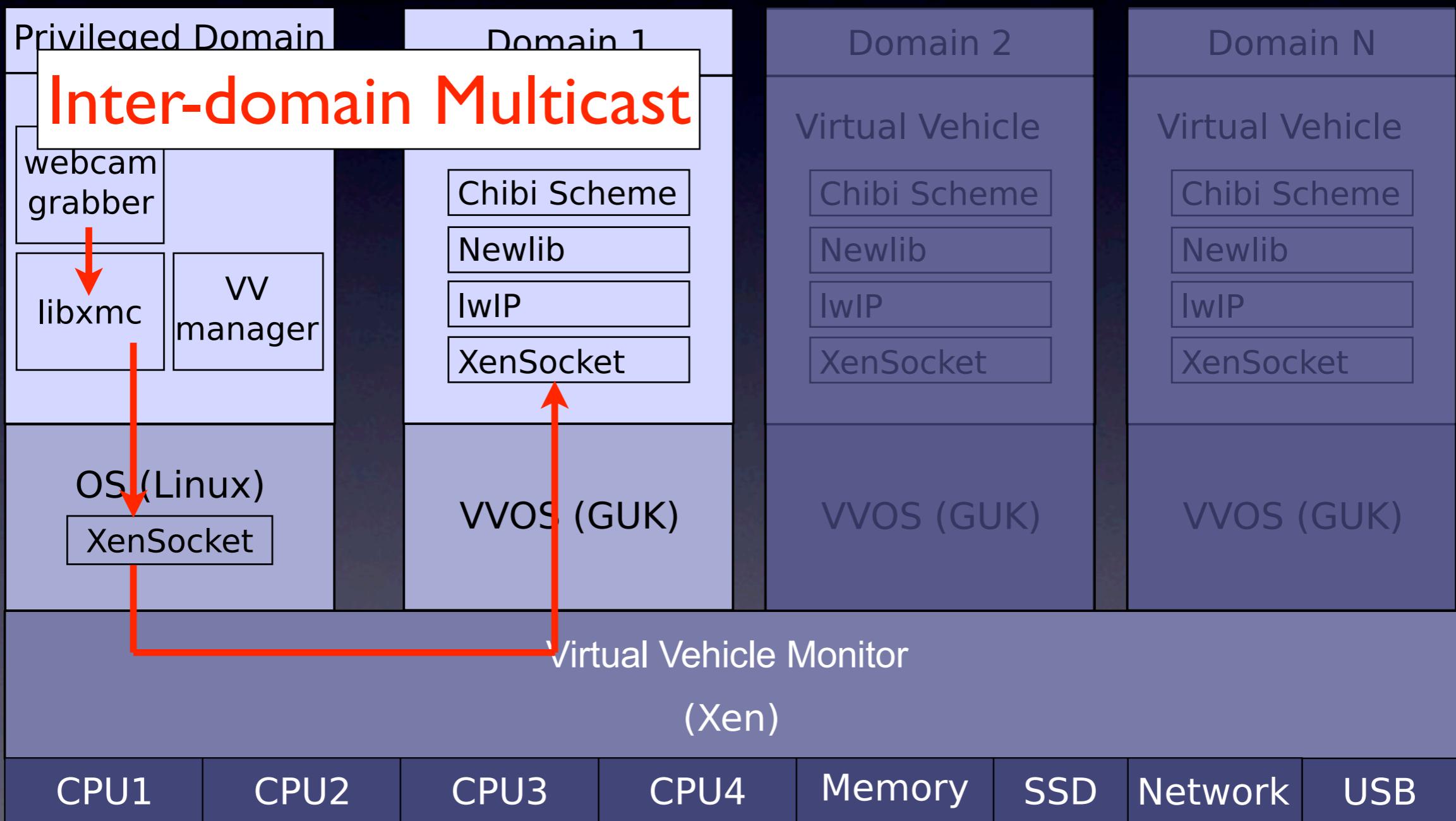
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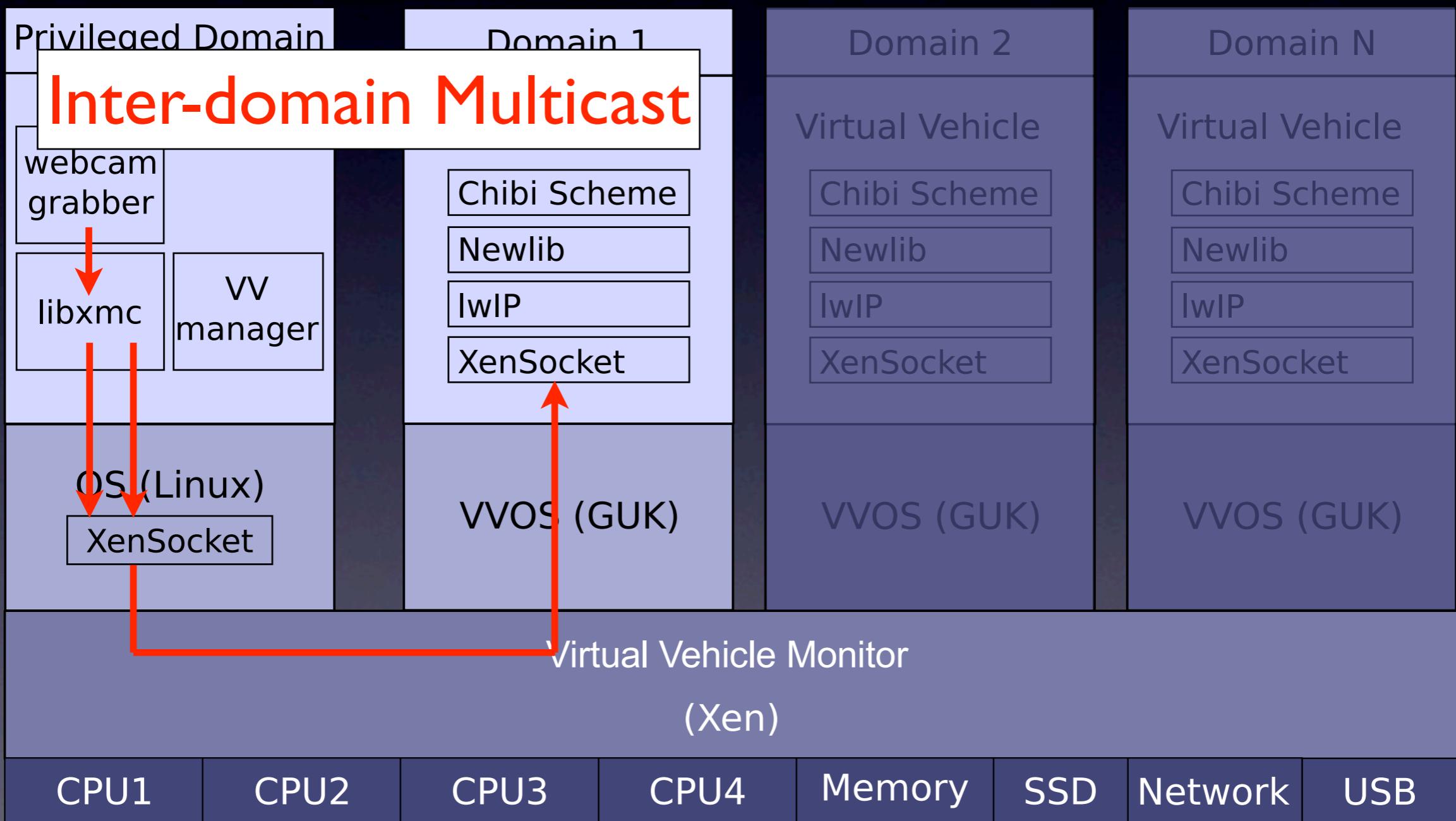
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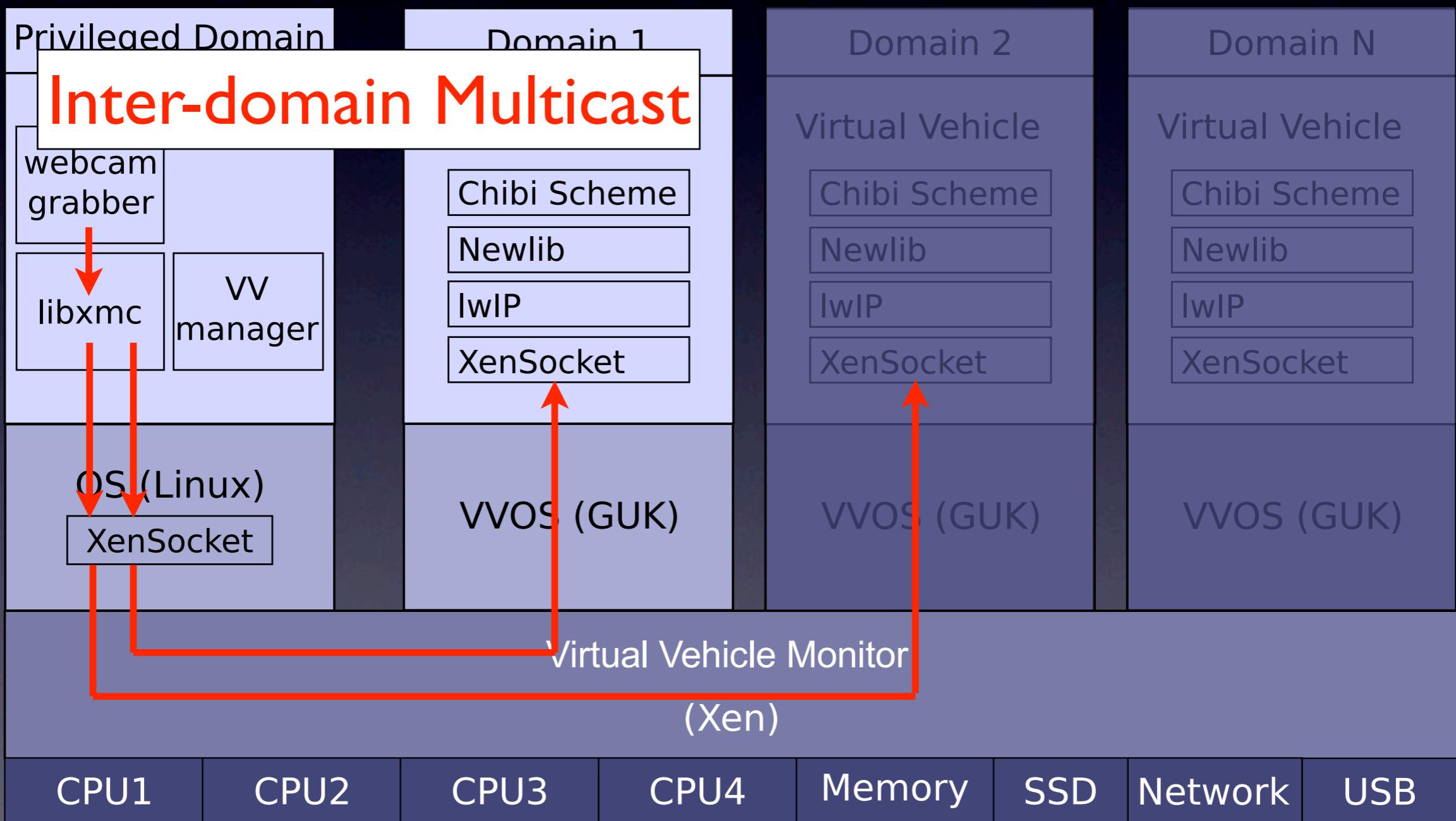
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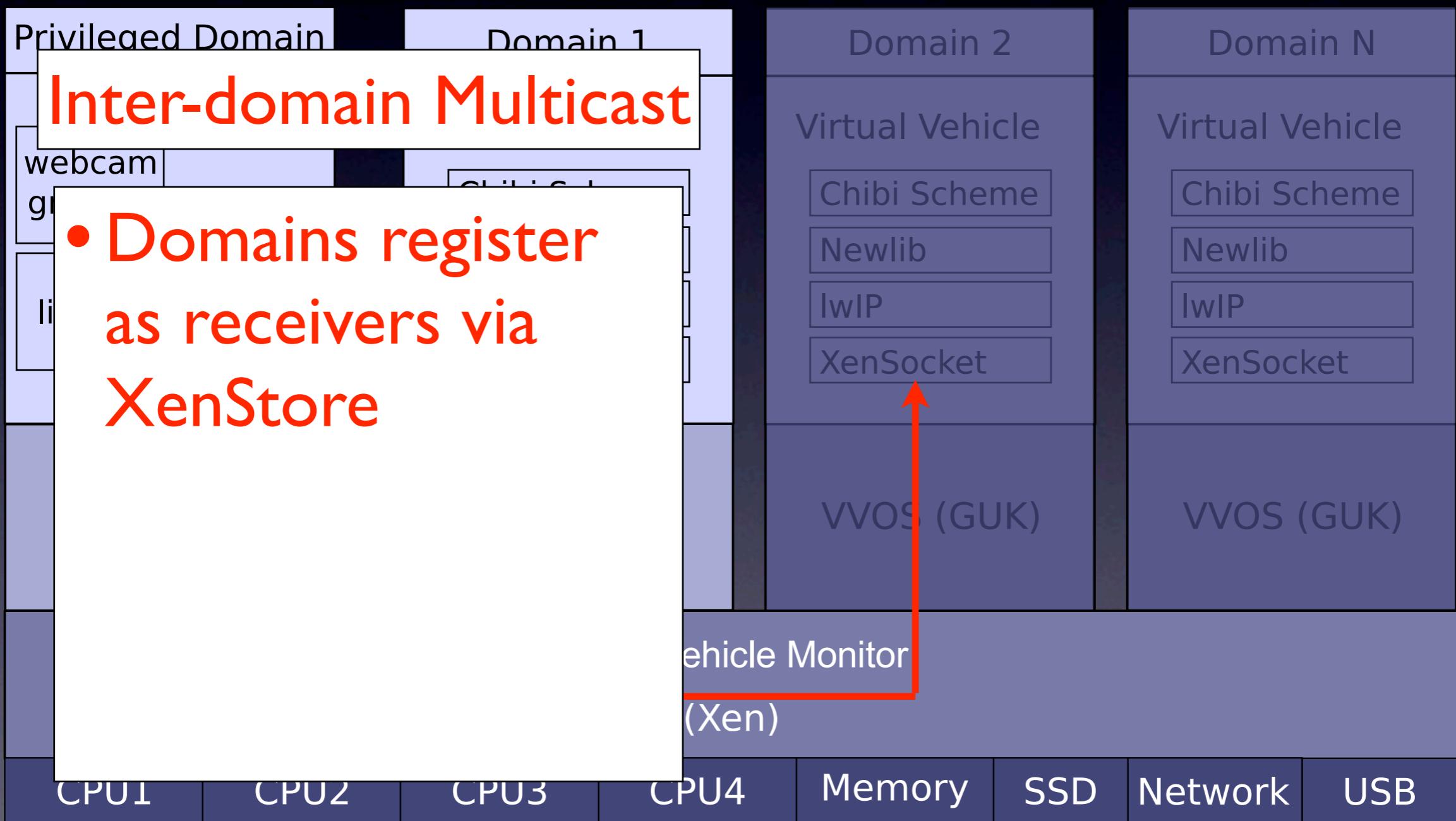
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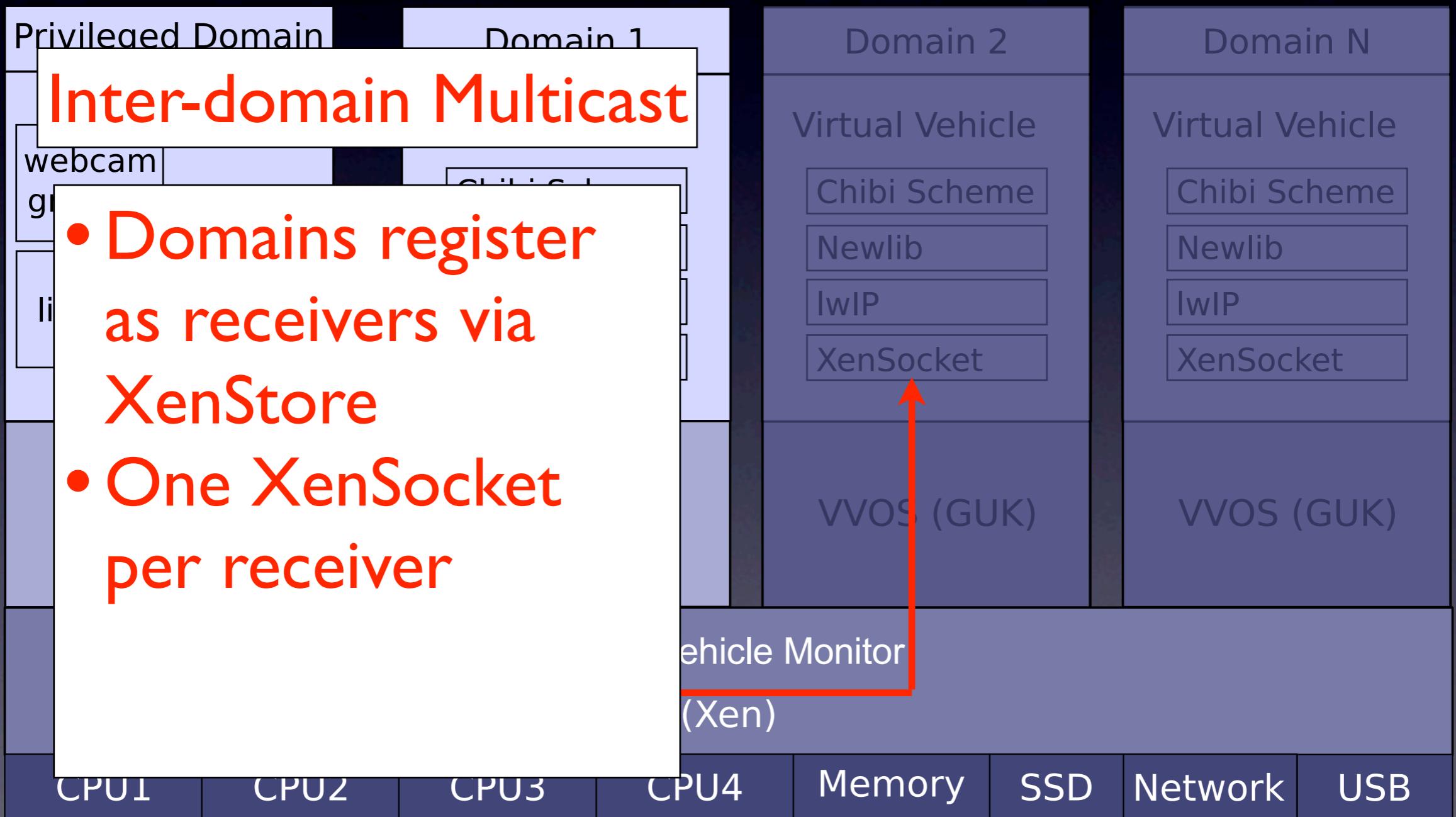
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- Domains register as receivers via XenStore

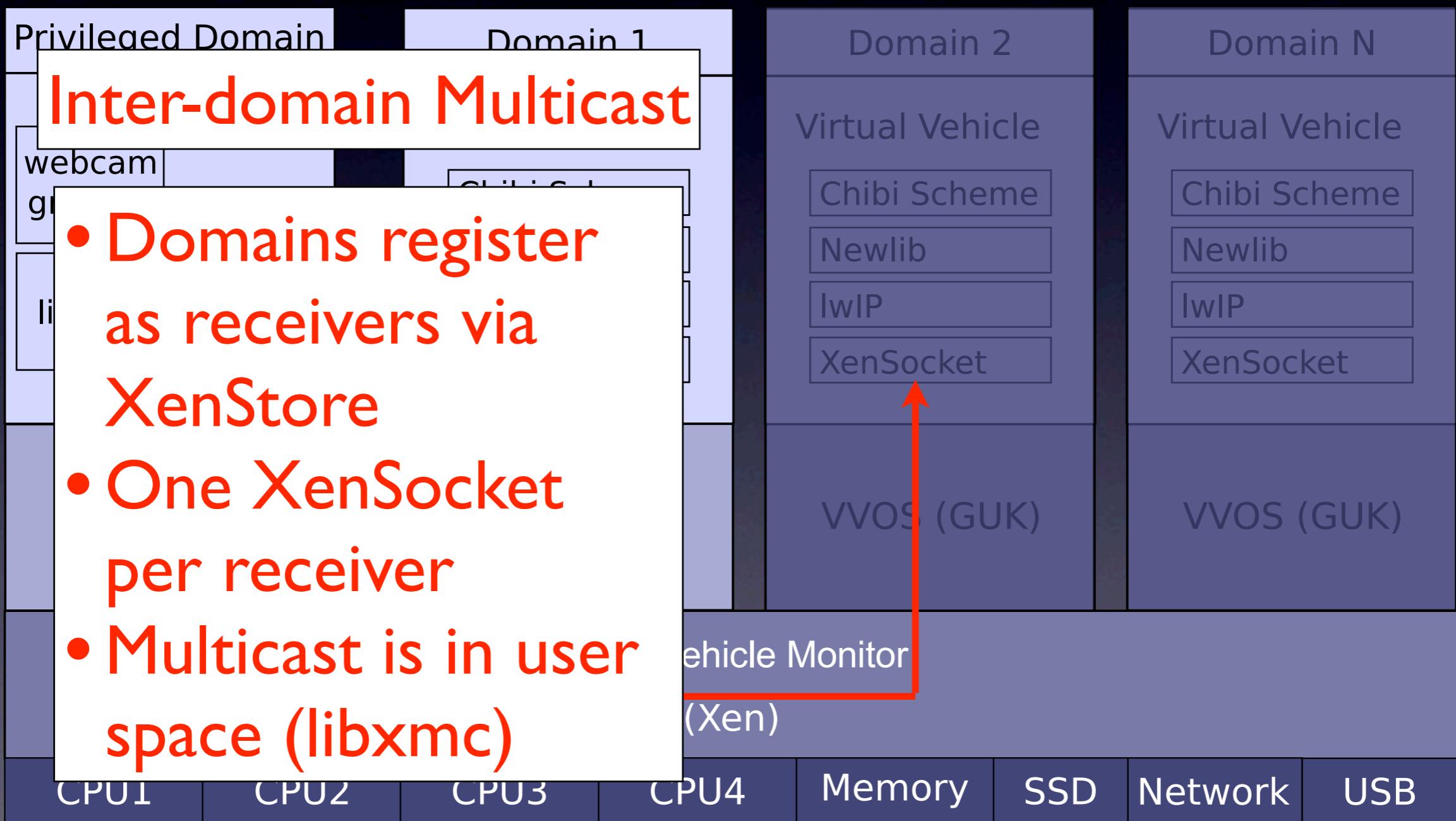
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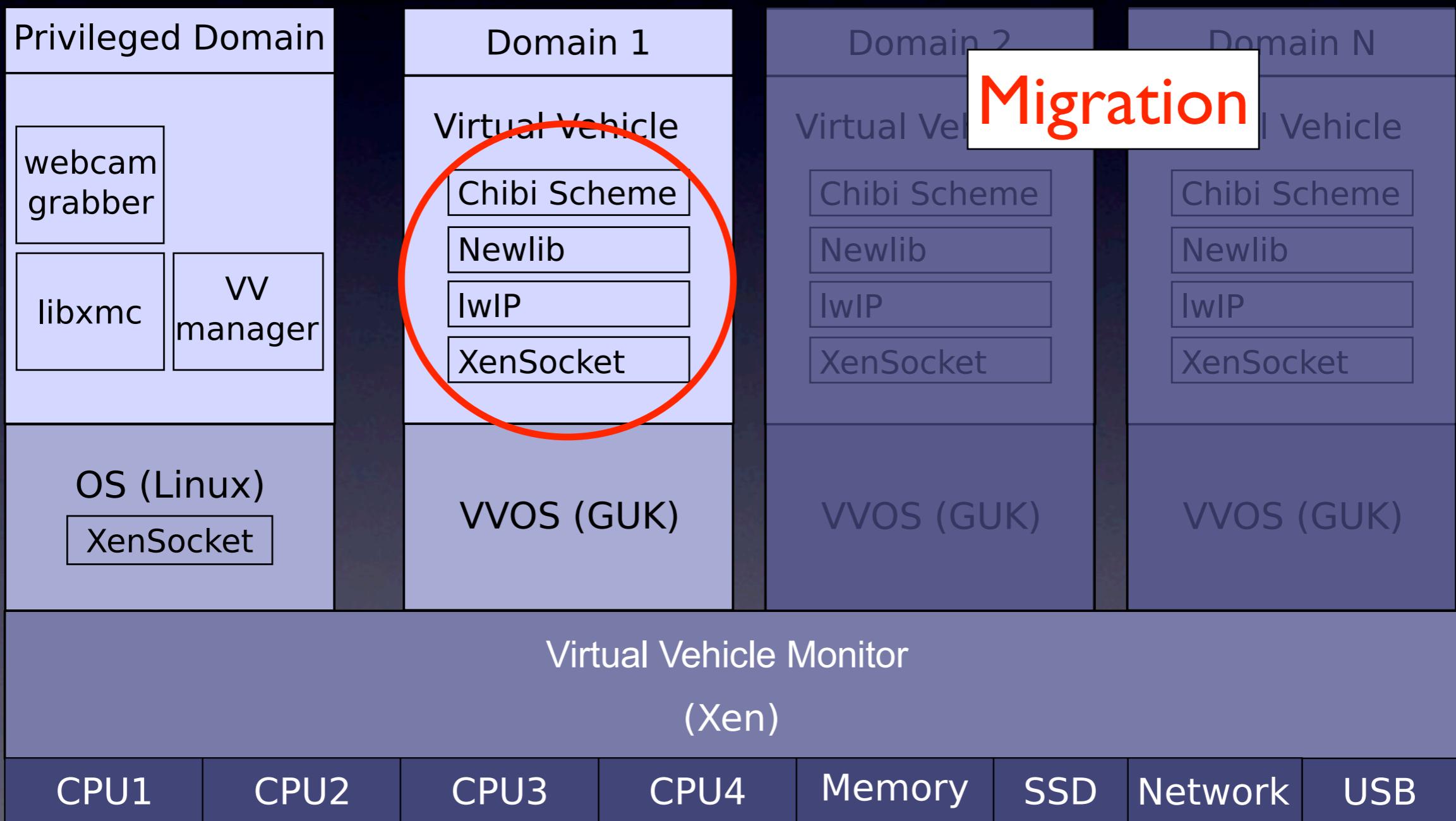
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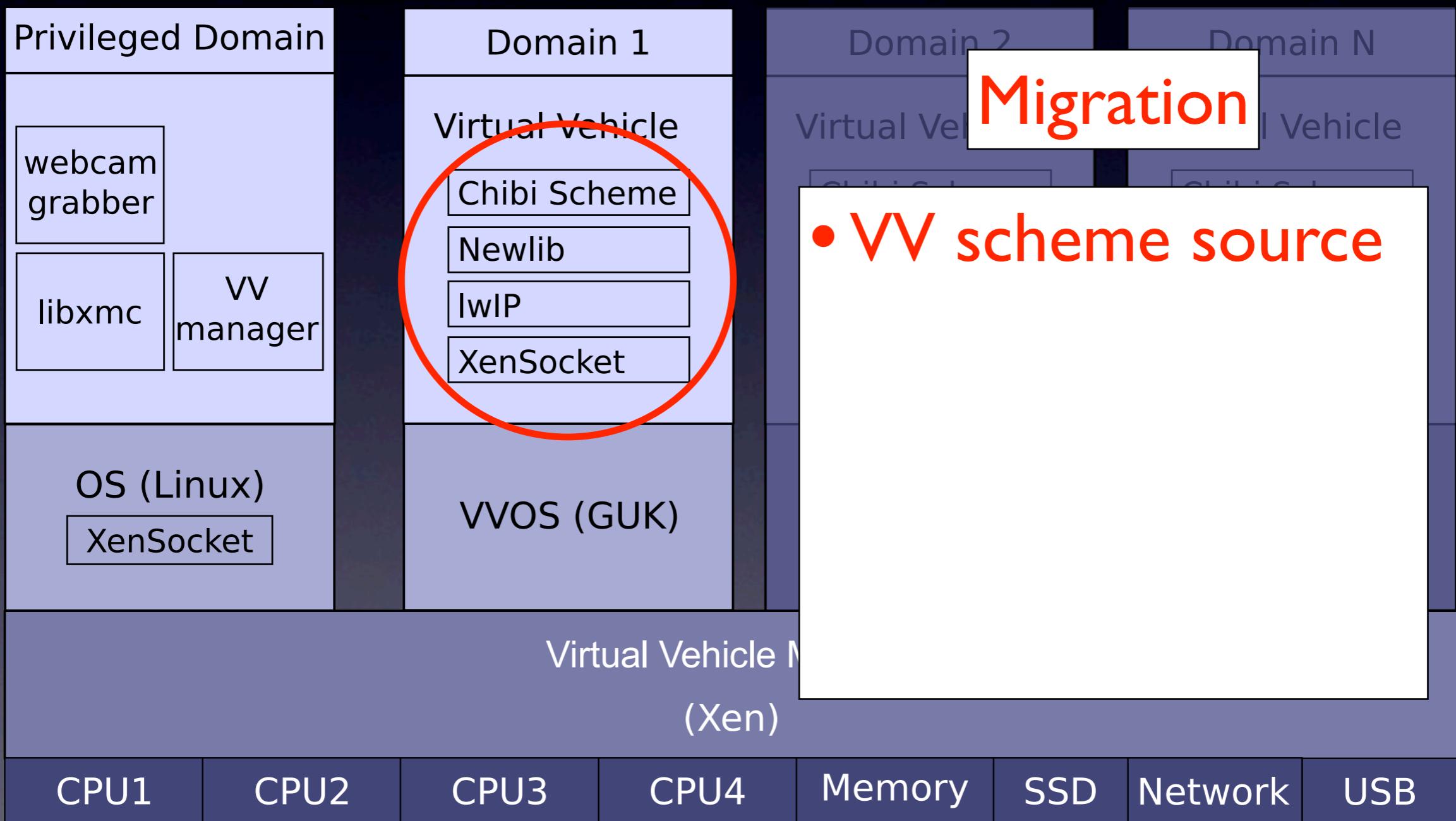
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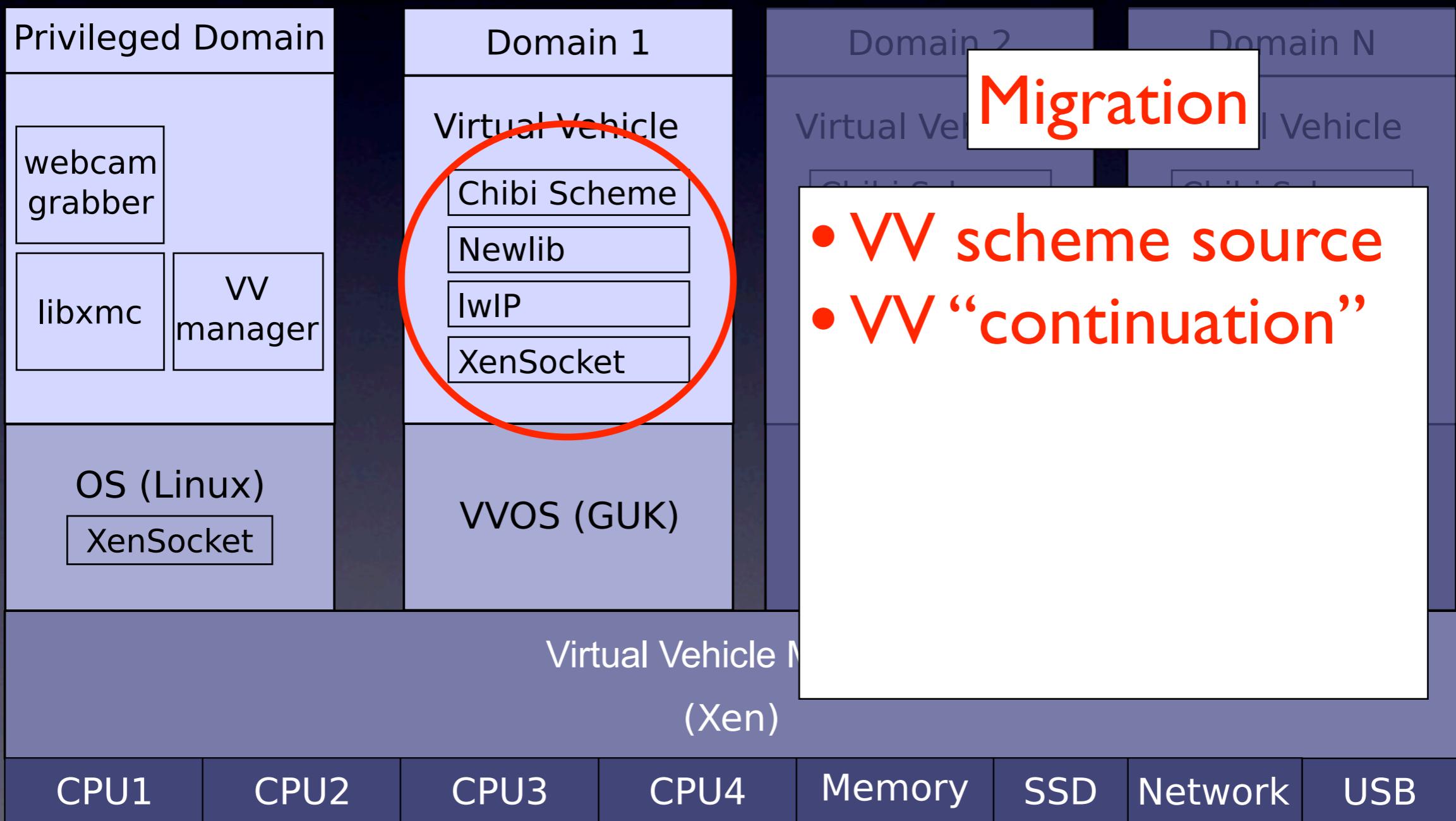
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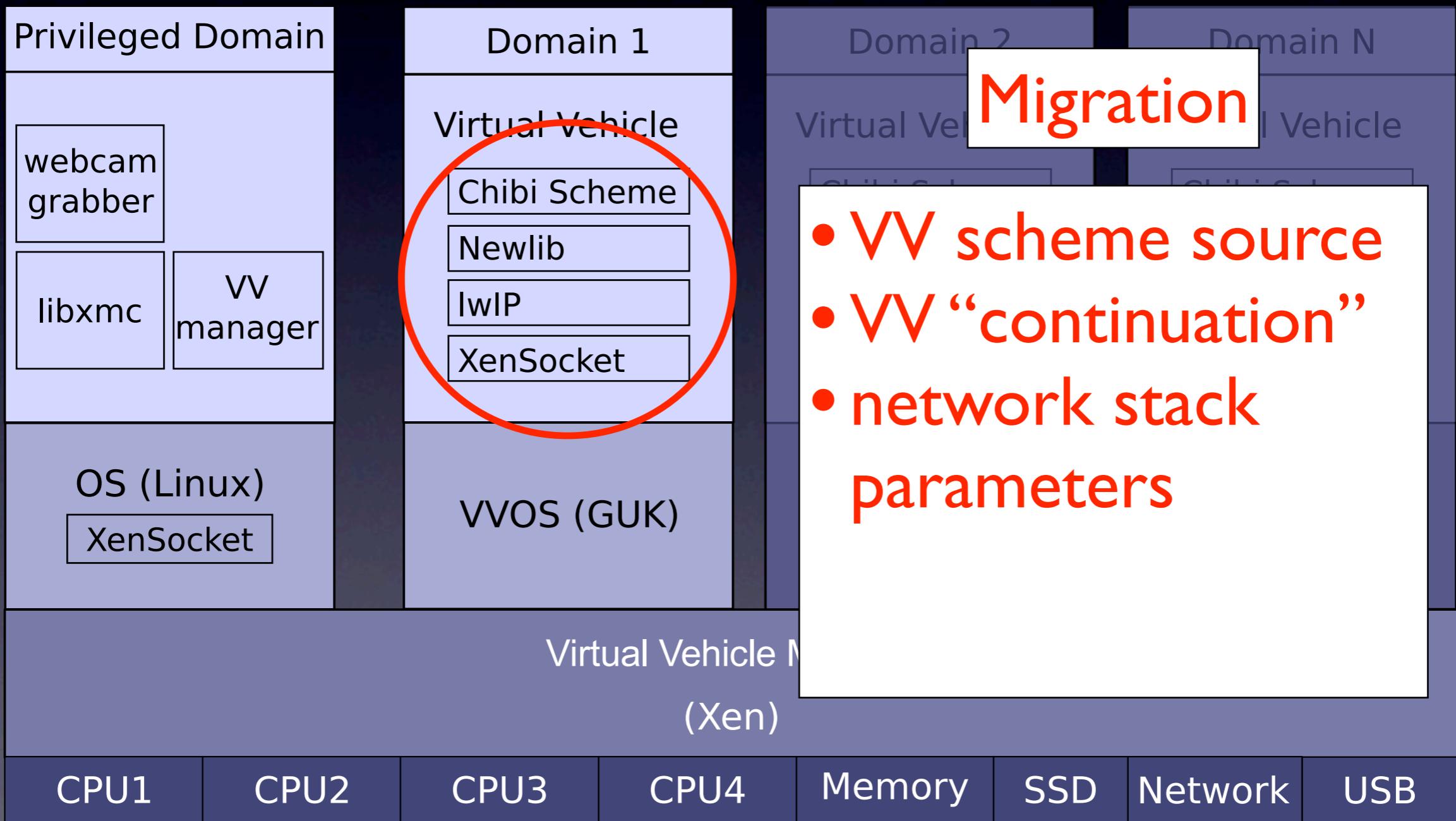
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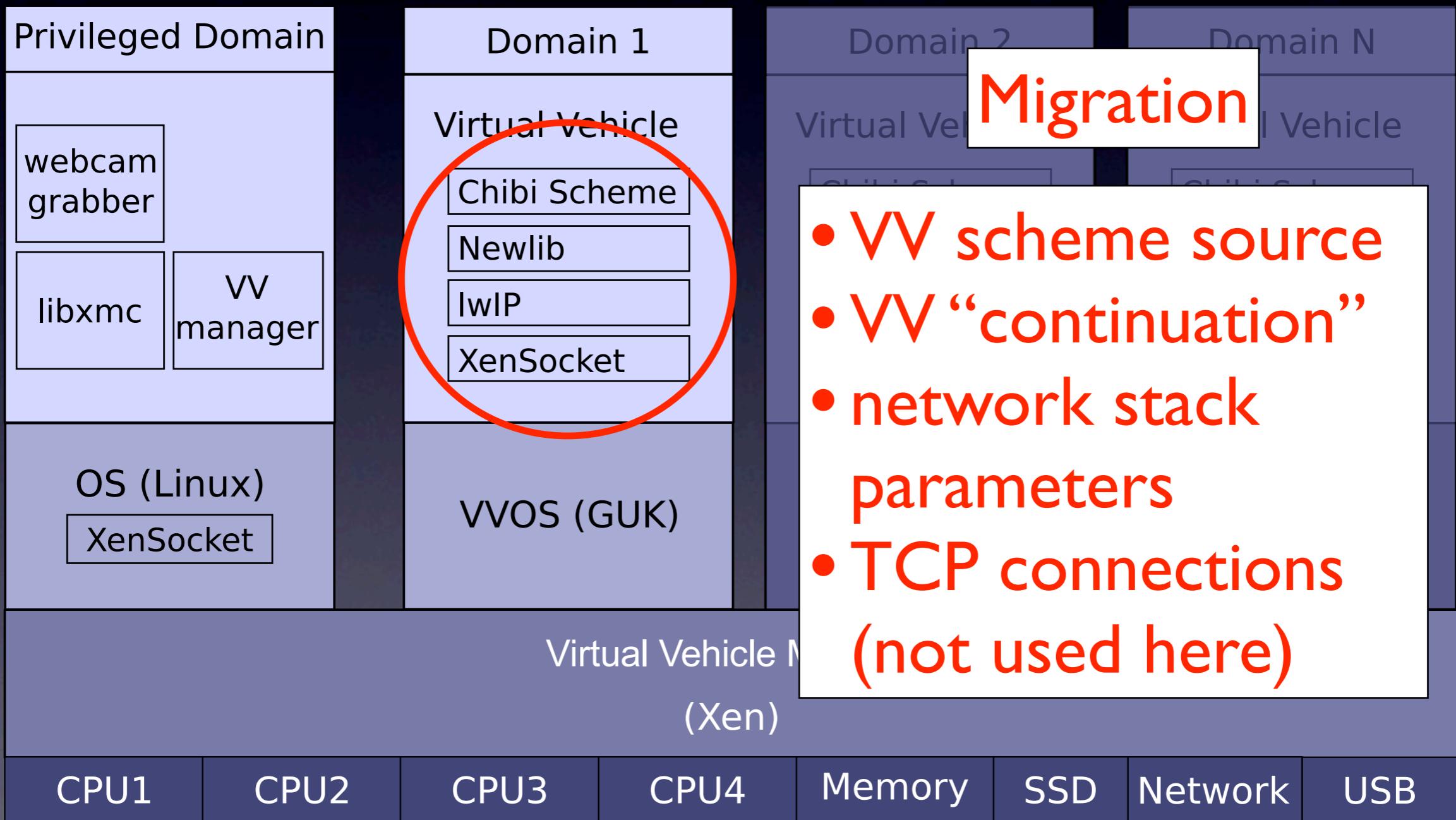
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3 VVs on 2 Servers

Virtual volumes are mapped to physical volumes on two servers.

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3 Ws on 2 Servers

NAME	STATE	CPU(sec)	CPU(%)	MEM(k)	MEM(%)	MAXMEM(k)	MAXMEM(%)
Domain-0	----r	86328	46.0	3741852	93.7	no limit	n/a
tramp-1	--b---	0	0.3	31744	0.8	32768	0
tramp-3	--b---	0	16.1	31744	0.8	32768	0
tramp-4	--b---	0	0.0	31744	0.8	32768	0
tramp-5	--b---	0	0.0	31744	0.8	32768	0
tramp-6	--b---	0	0.0	31744	0.8	32768	0
tramp-7	----p-	0	0.0	31744	0.8	32768	0

```

flandolt@big-iron1: ~
top - 18:20:14 up 50 days, 2:38, 12 users, load average: 0.14, 0.06
Tasks: 190 total, 3 running, 184 sleeping, 3 stopped, 0 zombie
Cpu(s): 2.1%us, 1.6%sy, 0.0%ni, 96.0%id, 0.0%wa, 0.0%hi, 0.2%si
Mem: 3665672k total, 3588908k used, 76764k free, 315488k buff
Swap: 3903752k total, 0k used, 3903752k free, 1883756k cach

```

PID	USER	PR	NI	VIRT	RES	SHR	S	%CPU	%MEM	TIME+	COMMAND
6773	root	20	0	52656	11m	3136	S	8	0.3	0:00.25	xm
4311	root	20	0	231m	18m	2252	S	5	0.5	46:40.89	xend
28568	root	20	0	117m	9.9m	4220	S	5	0.3	135:42.45	Xorg
4302	root	20	0	8628	1132	624	R	4	0.0	1:16.80	xenstored
1531	flandolt	20	0	31300	1848	1484	S	1	0.1	0:03.26	bouboule
28909	flandolt	20	0	19212	1480	1072	R	1	0.0	0:59.00	top

```
delay Networks vcds mem VCPUs Repeat header Sort order Quit
flandolt@big-iron1: ~/mt_docs/xen/archi
big-iron1$ sudo ./webFeed
Creating channel
-----src_fmt pixfmt:
RGB3
-----dst_fmt pixfmt:
MJPG
transferring data to: 2 domain(s)

flandolt@big-iron3: ~/m
big-iron3$ sudo ./webfeed
Creating channel
-----src_fmt pixfmt:
RGB3
-----dst_fmt pixfmt:
MJPG
transferring data to: 1 domain(s)
```

```
[docs/xen/archi] flandolt@big-iron1: /home/rotty/src/guk-new/tramp
got line: Using config File "/tmp/trampd-cfg.sYrU2R".
got line: Started domain tramp-6 (id=199)
vm-pool: enqueued domain 199
Client 192.168.1.171:4098 accepted...
vm-pool: dequeued domain 196
Initiating state transfer with domain 196
vm-pool: creating new domain; name=tramp-7, ip=192.168.1.206
% xm create -p /tmp/trampd-cfg.5FqQ0i
Waiting for domain 196 to become ready for state transfer
Copying state (3365 bytes) to domain 196...
Copying done.
Client 192.168.1.171:4098 done.
got line: main tool
got line: Using config File "/tmp/trampd-cfg.5FqQ0i".
got line: Started domain tramp-7 (id=200)
vm-pool: enqueued domain 200
]
```

```
flandoit@big-iron3: /home/rotty/src/guk-new/tramp      flandoit@bi
got line: Started domain tramp-4 (id=134)
vr-pool: enqueued domain 134
Client 127.0.0.1:38129 accepted...
vr-pool: dequeued domain 131
Initiating state transfer with domain 131
vr-pool: creating new domain: name=tramp-5, ip=192.168.1.204
Z xm create -p /tmp/trampd-cfg.ll4gIR
Waiting for domain 131 to become ready for state transfer
Copying state (3298 bytes) to domain 131...
Copying done.
Client 127.0.0.1:38129 done.
got line: main tool
got line: Using config file "/tmp/trampd-cfg.ll4gIR".
got line: Started domain tramp-5 (id=135)
vr-pool: enqueued domain 135
Client 192.168.1.171:4097 accepted...
vr-pool: dequeued domain 132
Initiating state transfer with domain 132
vr-pool: creating new domain: name=tramp-6, ip=192.168.1.205
Z xm create -p /tmp/trampd-cfg.MFJug0
Waiting for domain 132 to become ready for state transfer
Copying state (3440 bytes) to domain 132...
Copying done.
Client 192.168.1.171:4097 done.
got line: main tool
got line: Using config file "/tmp/trampd-cfg.MFJug0".
got line: Started domain tramp-6 (id=136)
vr-pool: enqueued domain 136
n
```

```
iron1: /home/rotty/src/guk-new/tramp
: -i 192.168.1.171 --gw 192.168.1.1 --netmask 255.255.255.0 scheme-apps/demo.scm scheme-apps/config/demo/ve
: -i 192.168.1.171 --gw 192.168.1.1 --netmask 255.255.255.0 scheme-apps/demo.scm scheme-apps/config/demo/ve

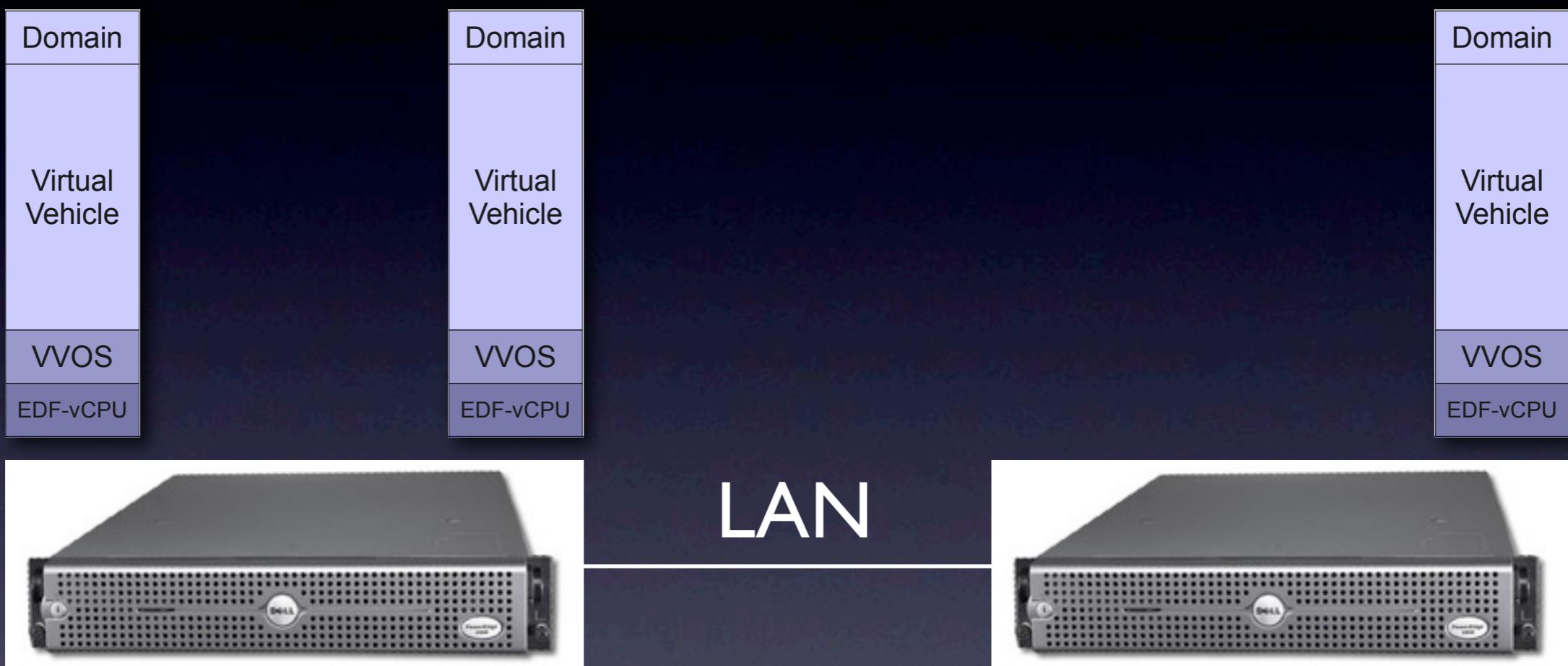
iron3: /home/rotty/src/guk-new/tramp
: -i 192.168.1.173 --gw 192.168.1.1 --netmask 255.255.255.0 scheme-apps/demo.scm scheme-apps/config/demo/ve
```

A screenshot of a video player window titled "udp://:12346 - VLC media player". The video frame shows a dark scene with several bright, glowing purple particles or stars scattered across it. In the bottom right corner of the video frame, there is a white rectangular box containing the text "Migrating from machine 2 to 1" in a large, sans-serif font.

A screenshot from a VLC media player window titled "udp://:12347 - VLC media player". The video frame shows a light blue background with several green, three-dimensional puzzle piece shapes floating in the air.

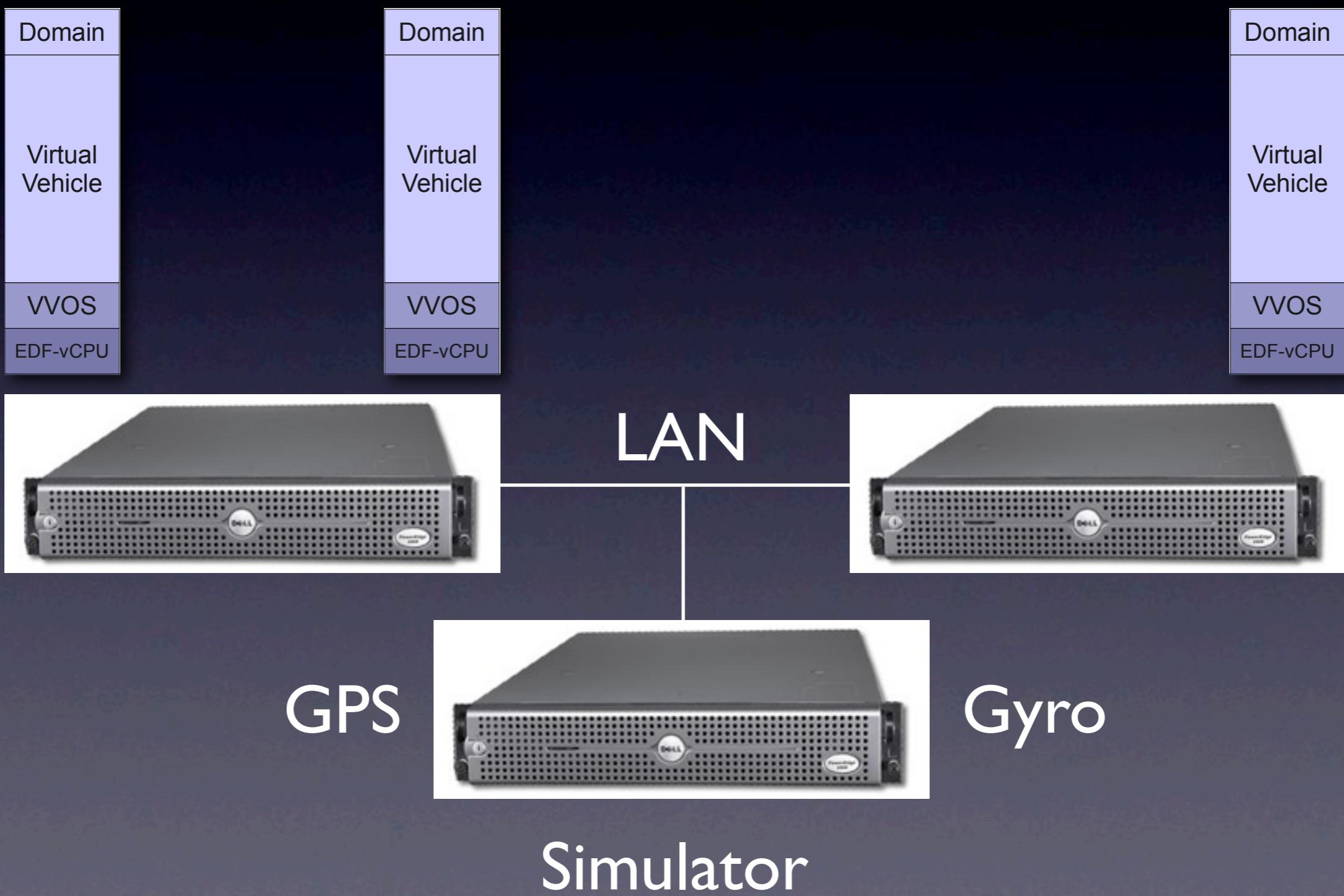
Future Work

(Simulating Motion, Flying Real Vehicles)



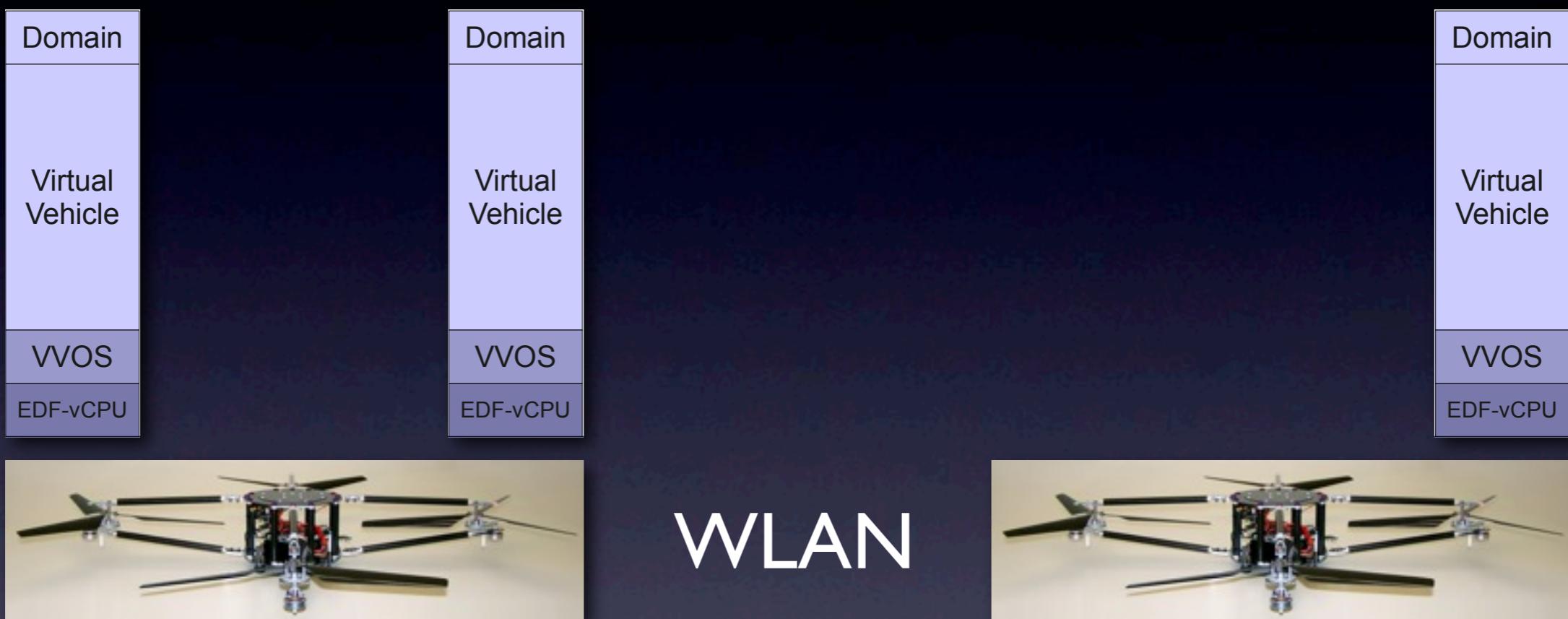
Future Work

(Simulating Motion, Flying Real Vehicles)



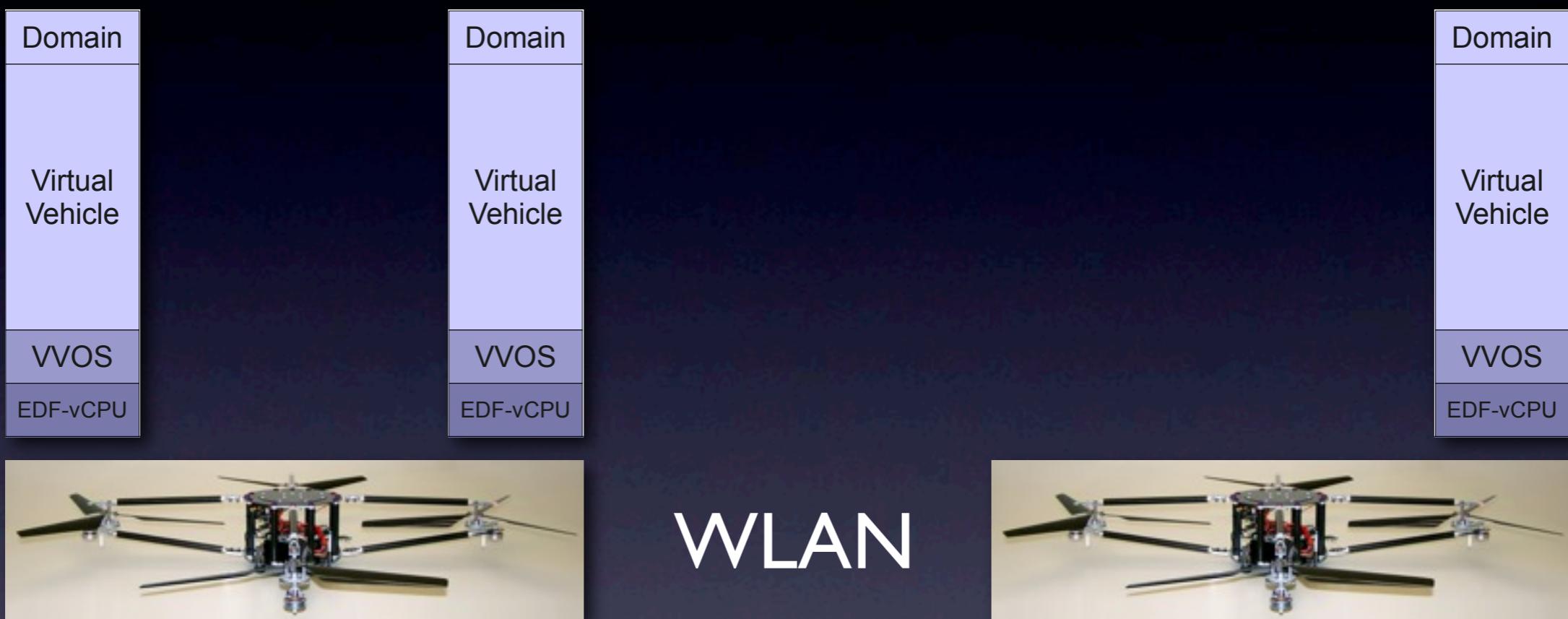
Future Work

(Simulating Motion, Flying Real Vehicles)



Future Work

(Simulating Motion, Flying Real Vehicles)

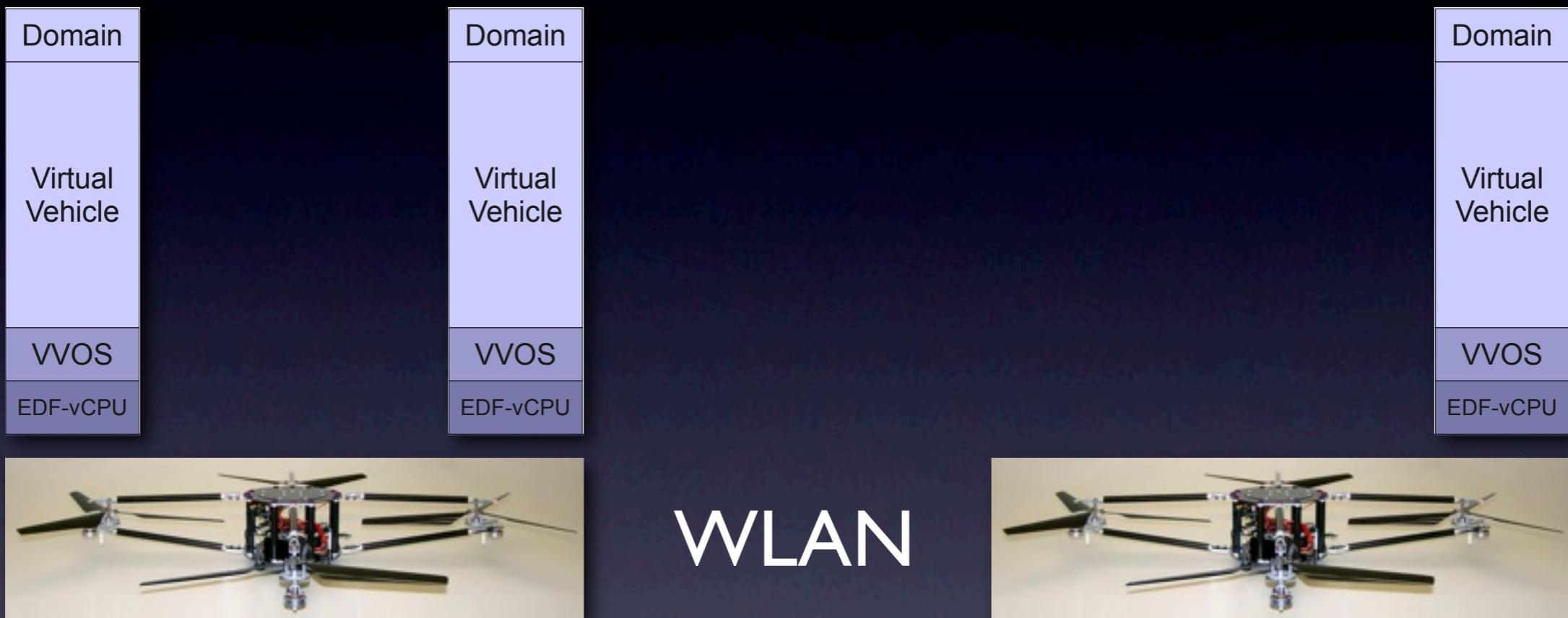


WLAN

- **read-only, scheduled real vehicle flight plans:**

Future Work

(Simulating Motion, Flying Real Vehicles)



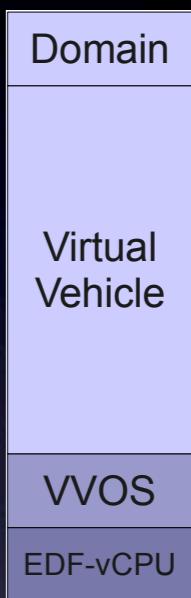
- **read-only, scheduled real vehicle flight plans:**
 - ▶ **virtual-to-real** vehicle allocation problem

Future Work

(Simulating Motion, Flying Real Vehicles)



WLAN



- **read-only**, scheduled real vehicle flight plans:
 - ▶ **virtual-to-real** vehicle allocation problem
- **read-write**, on demand real vehicle flight plans:

Future Work

(Simulating Motion, Flying Real Vehicles)



WLAN

- **read-only**, scheduled real vehicle flight plans:
 - ▶ **virtual-to-real** vehicle allocation problem
- **read-write**, on demand real vehicle flight plans:
 - ▶ **real-to-virtual** vehicle allocation problem



Thank you

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