LUND UNIVERSITY

AXIS COMMUNICATIONS

Camera Networks Dimensioning and Scheduling with Quasi Worst-Case Transmission Time

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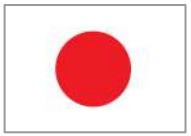
WASP | WALLENBERG AI, AUTONOMOUS SYSTEMS AND SOFTWARE PROGRAM

Who are we ?

- Swedish company 
- Since 1996 / Canon since 2015 
- ~3000 employees & 179 countries
- Development offices:
  - Lund
  - Linköping
  - Paris
  - Shanghai
- ~835 million € sales revenue
- We do (mainly) **network cameras** !

  (and we are the world's number 2 at it)

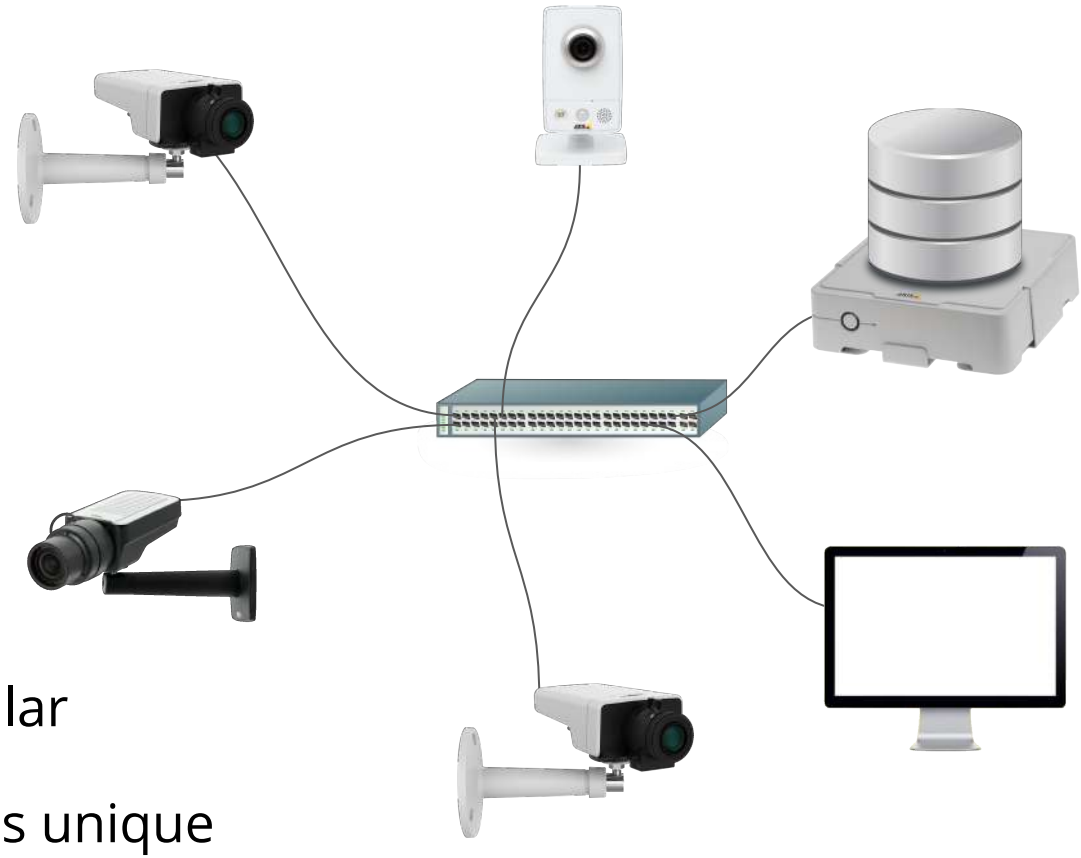
Network dimensioning ?

Dimensioning <> "long term"

How to design a system of cameras ?

How to estimate ?

- Storage space ?
- Network bandwidth ?
- Peak capacity ?



Knowing that:

- Each camera is unique

  ... but somewhat similar

- Each set-up/time period is unique

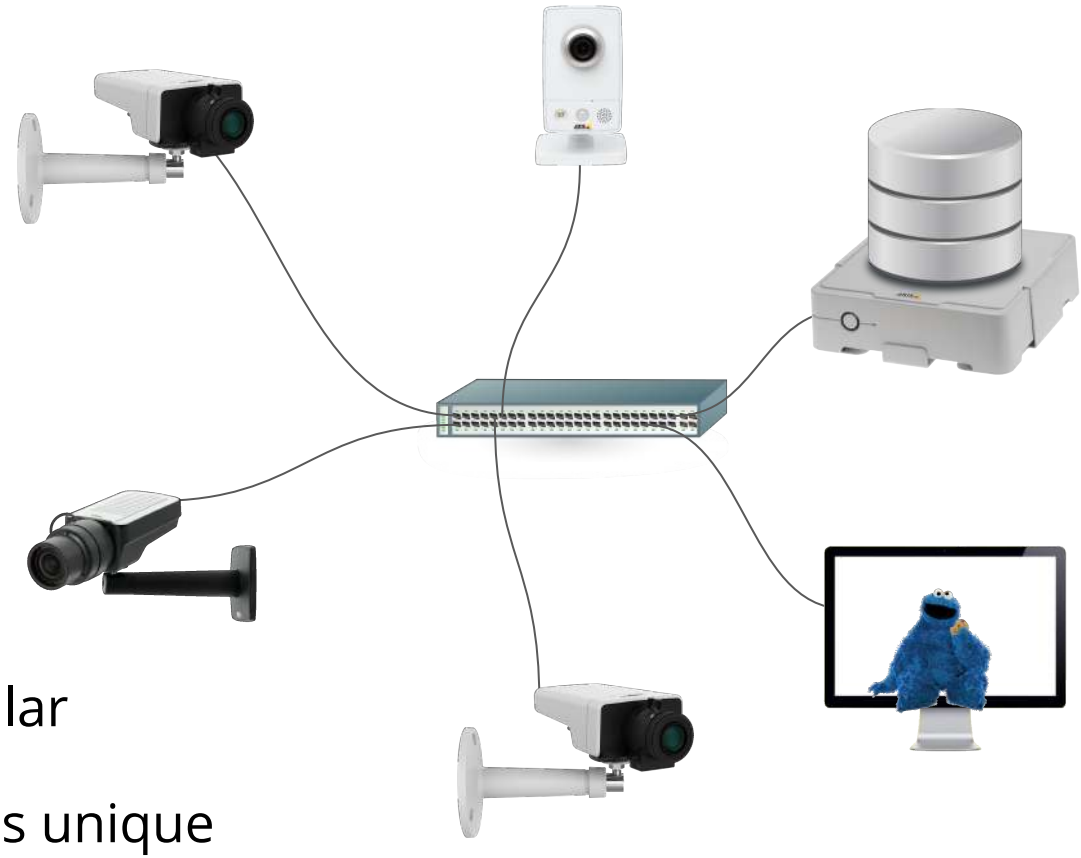
  ... but belongs to a limited category list

Network scheduling ?

Scheduling <> "short term"

How to estimate ?

- Maximum bandwidth ?
- Delay ?
- Peak capacity ?



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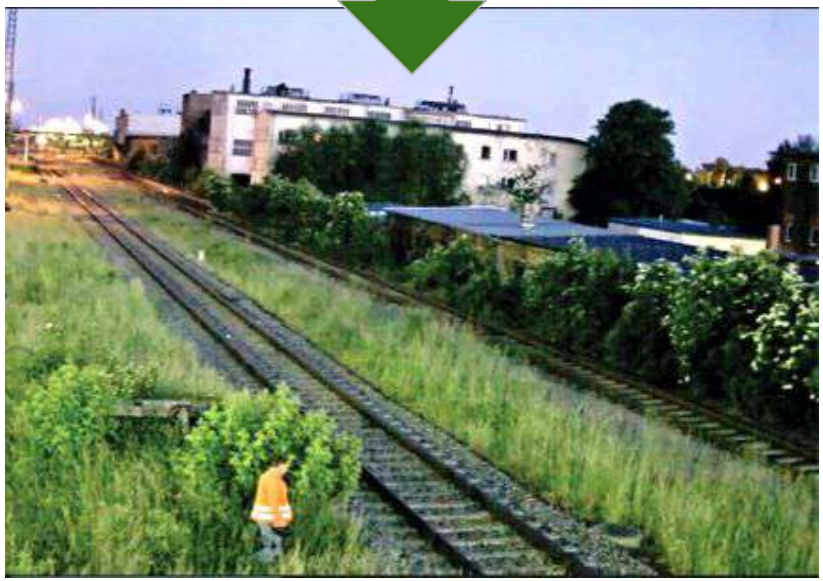
Video

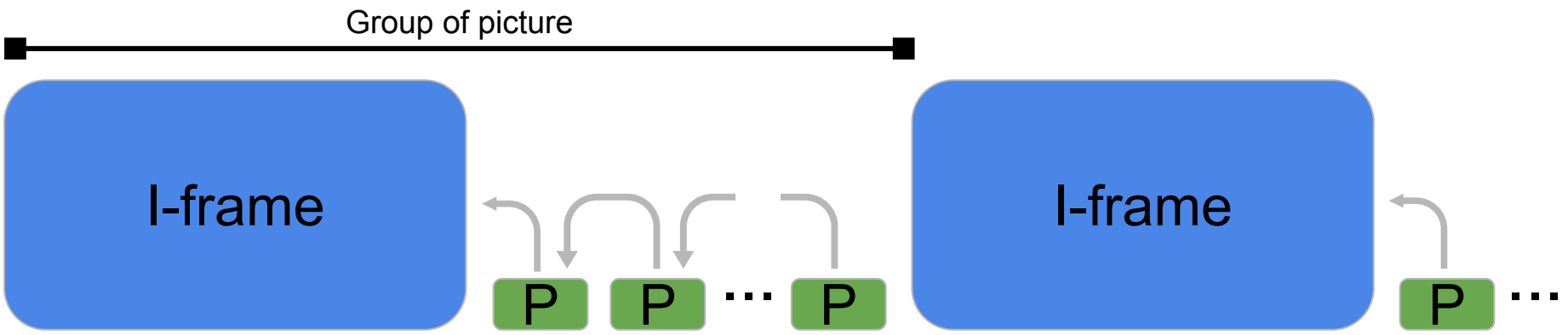


H.264

MJPEG

H.26x

* We consider B-frames equivalent to P-frames
* We consider I-frames as IDR frames



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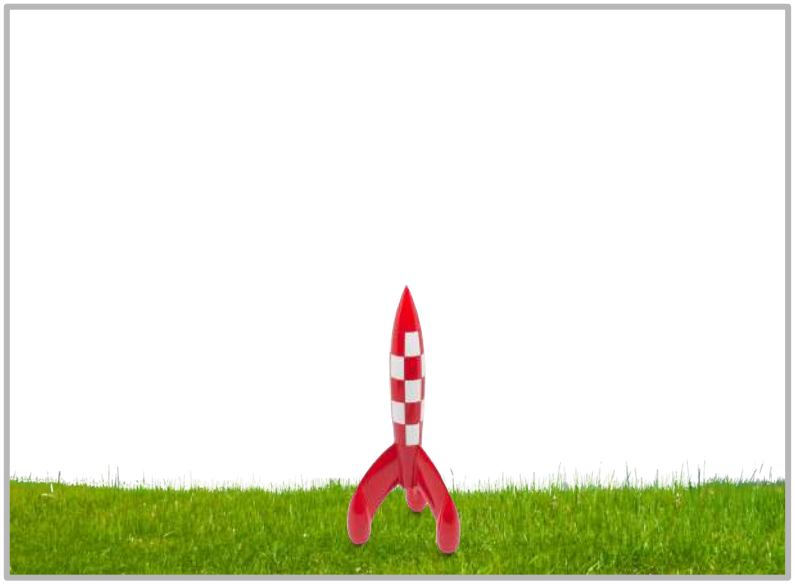

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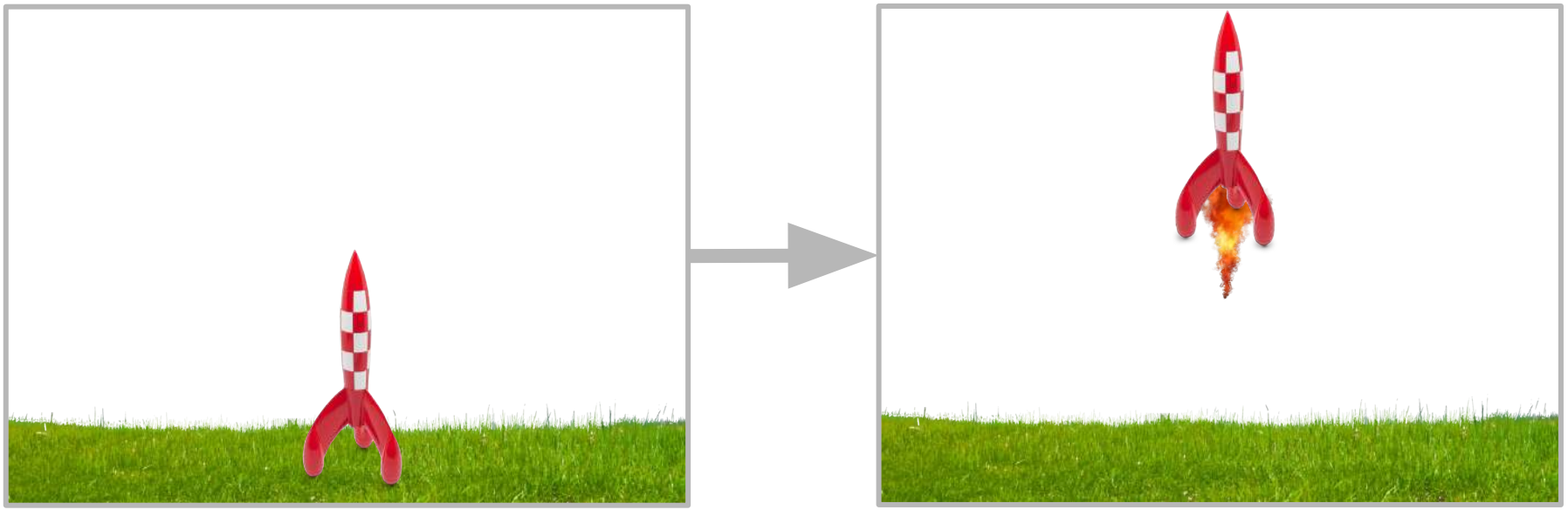

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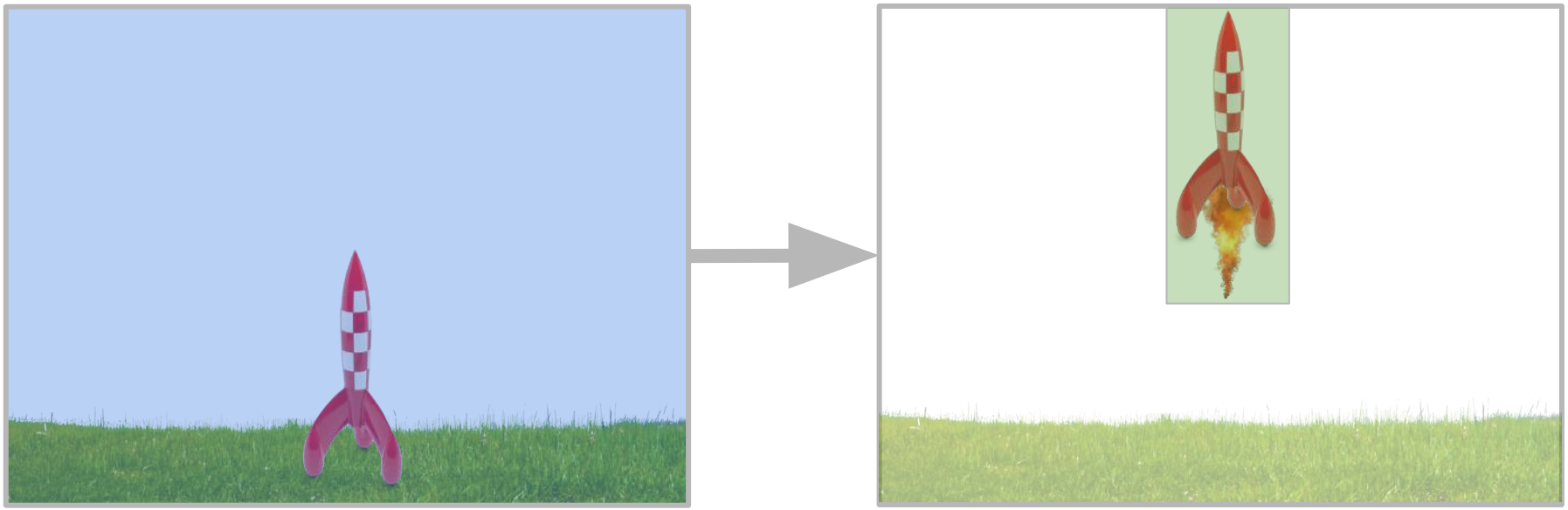

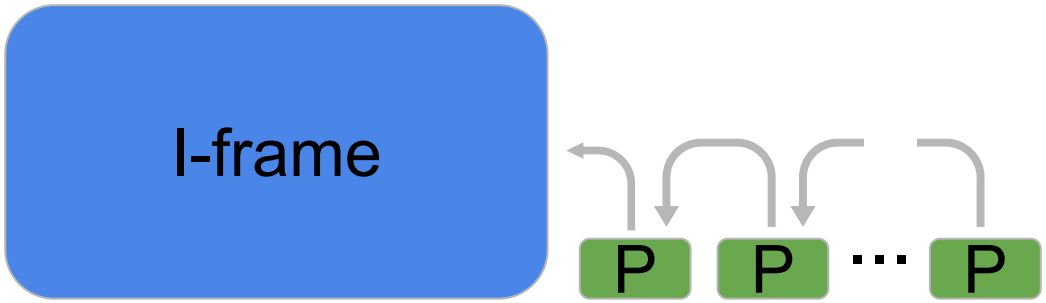

H.264

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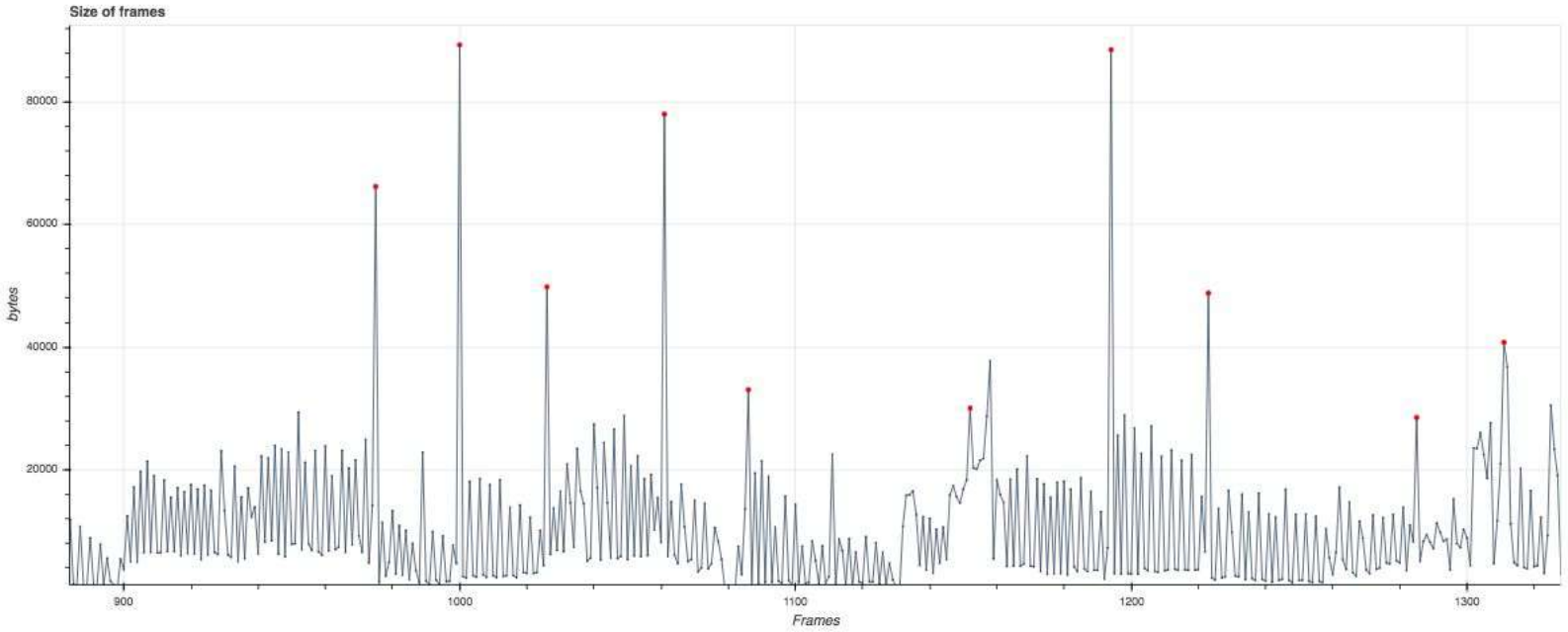


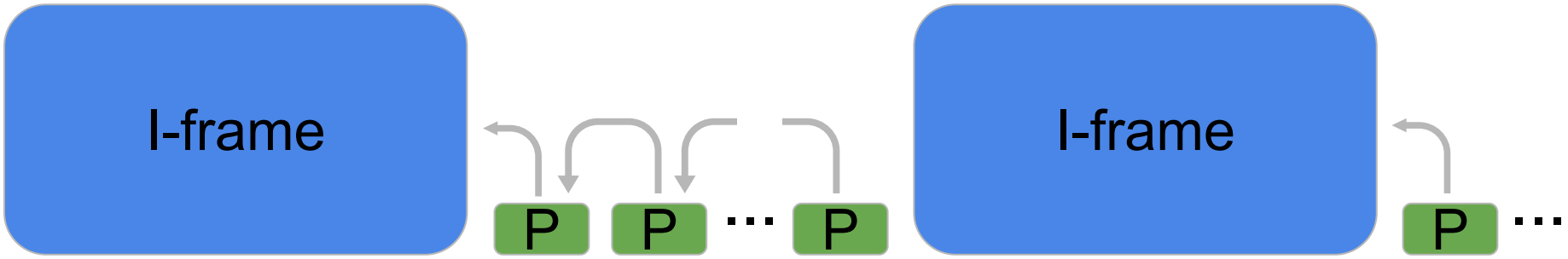
H.264 and scheduling

Multiframe model + Many cameras:

- I-frames
- B/P-frames

each generates a separate load

→ Paradigm: non-preemptive scheduling with multi-frame tasks



How do we dimension ?

Dimensioning Steps

- Characterize a **reference camera** model: in lab, in real scenarios
- Characterize **other camera** models: in lab, (in real scenarios)
- Characterize **scene types**: in real scenarios for different cameras
- Gather **scene/video parameters** (motion, light level, zoom, GOP, fps...)
  - Measurable in real time
  - Estimated from usage/placement
- Extrapolate **expected frame sizes** and bandwidth

How do we dimension ?

1. Parameters

	Platform	Camera model	Scene/video	Frame
Camera detail properties (D_C)		✓		
Camera noise (N_C)		✓		
Compression/QP				✓
Dynamic range factor (DR)			✓	
Frame rate (FPS)			✓	✓
Group of pictures (GOP)			✓	✓
h, w, resolution			✓	
Motion encoder efficiency (M_{EC})	✓			
Motion level (ML)				✓
Nature factor (N_F)			✓	
Scene detail level (D_S)			✓	
Scene illumination (L)			✓	✓
Size of Average Object (SAO)			✓	✓

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measured in laboratory

measured at runtime

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Camera

measured in laboratory

measured at runtime

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Size of Average Object (SAO)			✓	✓	Scene

measured in laboratory

measured at runtime

How do we dimension ?

2. I-frames

$$I = \left(D_S \times L \times D_C \times (1 + N_F) \times DR \times SAO + N_{C,L} \right) \times w \times h \times 2^{-\Delta QP/6}.$$

Scene **detail level** (how complex is the scene)

Scene **light level** (how much light)

Camera detail capability (how much does the camera retains details)

Nature factor (amount of nature)

Dynamic range

Size of average object (**lens, zoom…**)

Camera **noise** factor (how much noise from the camera)

Image **width & height**

Compression scaling (I-frame)

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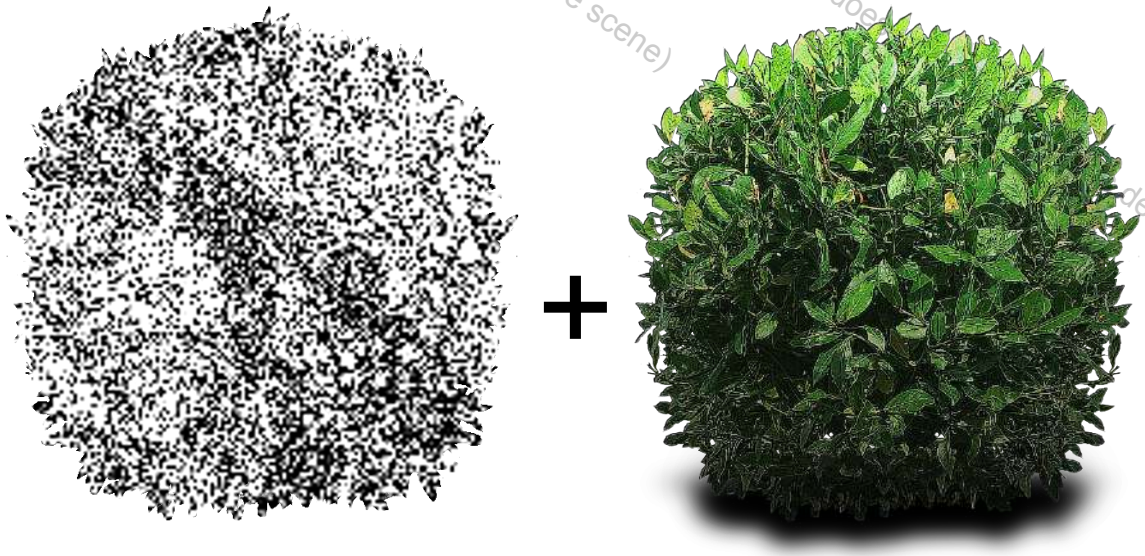

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Camera **noise** factor (how much noise fro

Image **width & height**

Compression scaling (I-frame)

details)

How do we dimension ?

2. I-frames

I_C <> size of each I pixel

$$I = \left(D_S \times L \times D_C \times (1 + N_F) \times DR \times SAO + N_{C,L}\right) \times w \times h \times 2^{-\Delta QP/6}.$$

- D_S: Scene **detail level** (how complex is the scene)
- L: Scene **light level** (how much light)
- D_C: **Camera detail** capability (how much does the camera retains details)
- N_F: **Nature** factor (amount of nature)
- DR: **Dynamic range**
- SAO: Size of average object (**lens, zoom…**)
- $N_{C,L}$: Camera **noise** factor (how much noise from the camera)
- $w \times h$: Image **width & height**
- $2^{-\Delta QP/6}$: **Compression** scaling (I-frame)

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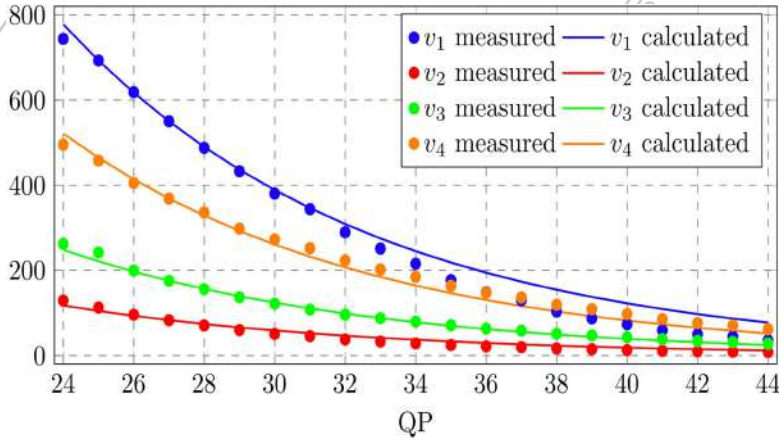
I_C

I-frame

QP +1
<>
quantization step + 12%



How do we dimension ?

3. P-frames

$$P = \left(ML_S \times clamp(\sqrt{\frac{FPS_{ref}}{FPS}}) \times I_C \times M_{EC} + N_{C,L} \right) \times w \times h \times 5^{-\Delta QP/6}.$$

Motion level

Frame rate & reference frame rate (how much changed)

Parenthesis part of **I**

Motion **encoder efficiency** (how good to find motion)

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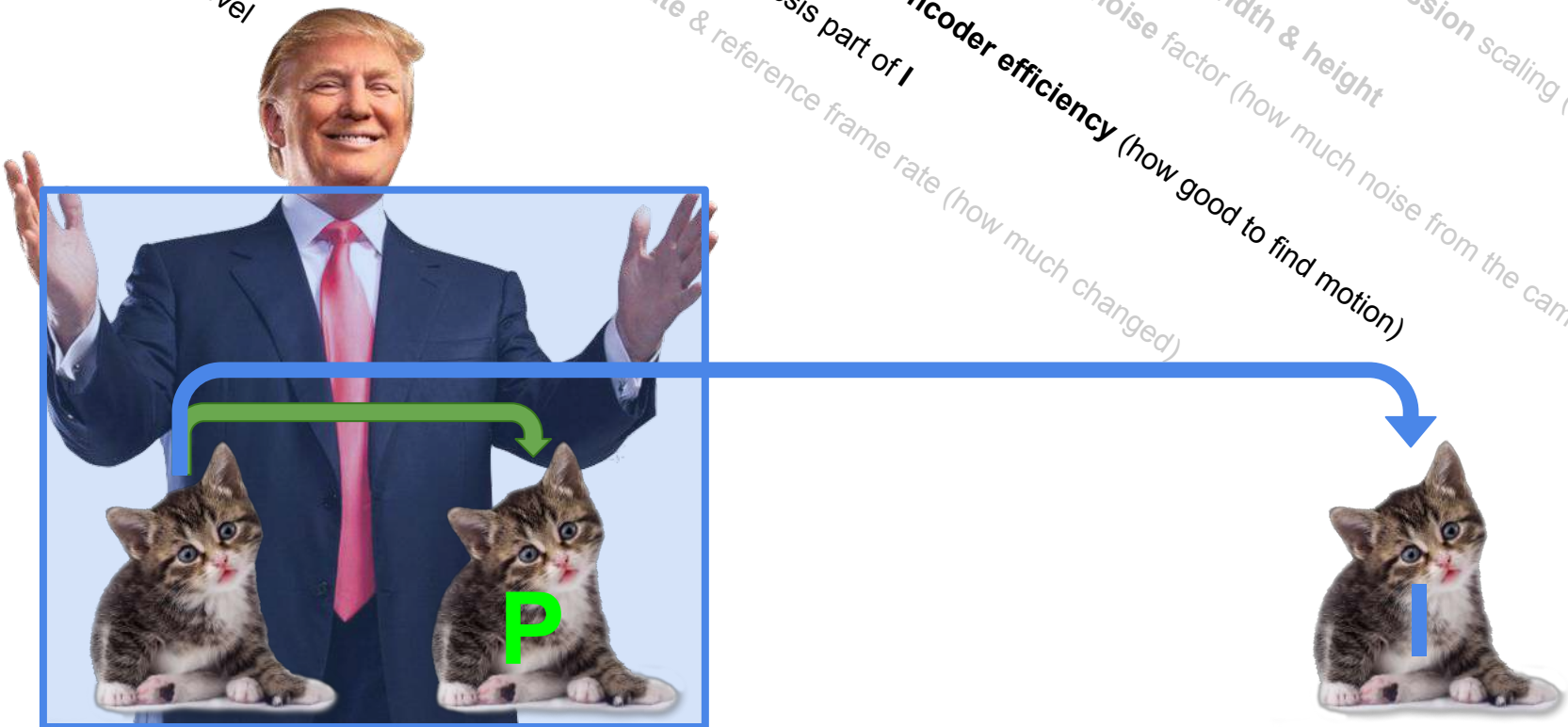

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Compression scaling (P-frame)

...1s

...10s

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Compression scaling (P-frame)

Keep "close" to reference: limit to [2 … 0.5]

7 … **30** … 120 fps

...1s

...10s

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P_C <> part of each " pixel"

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P_C <> part of each "I pixel"

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$$P = \left(ML_S \times clamp(\sqrt{\frac{FPS_{ref}}{FPS}}) \times I_C \times M_{EC} + N_{C,L}\right) \times w \times h \times 5^{-\Delta QP/6}.$$

Motion level

Frame rate & reference frame rate (how much changed)

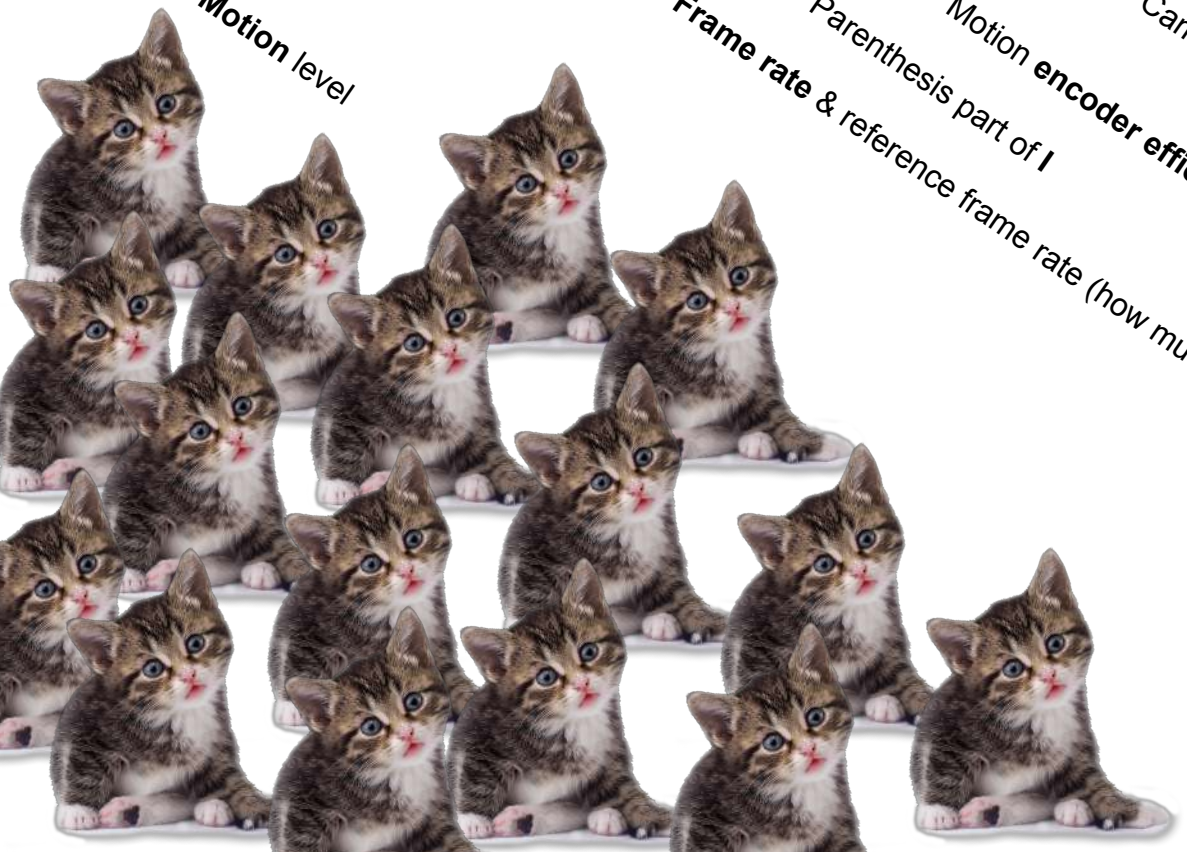
Parenthesis part of **I**

Motion **encoder efficiency** (how good to find motion)

Camera **noise** factor (how much noise from the camera)

Image **width & height**

Compression scaling (P-frame)



How do we dimension ?

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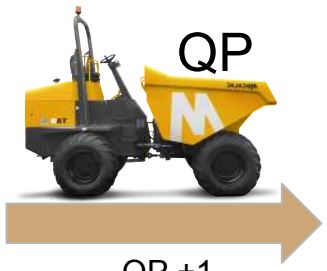
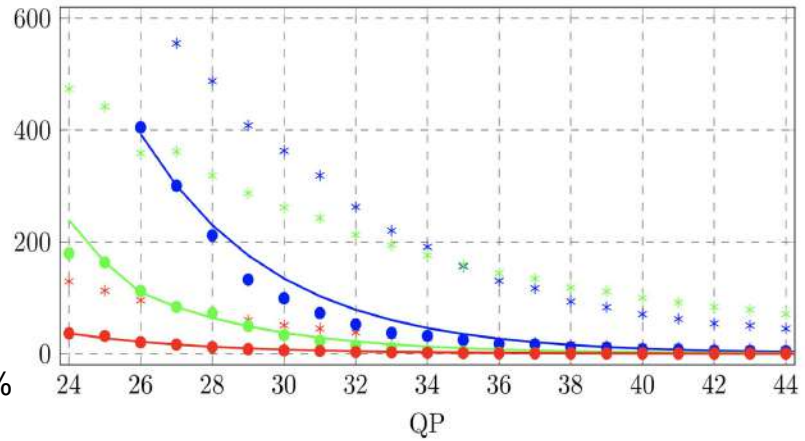
P_C P-frame



QP +1
<>
quantization step + 12%



How do we dimension ?

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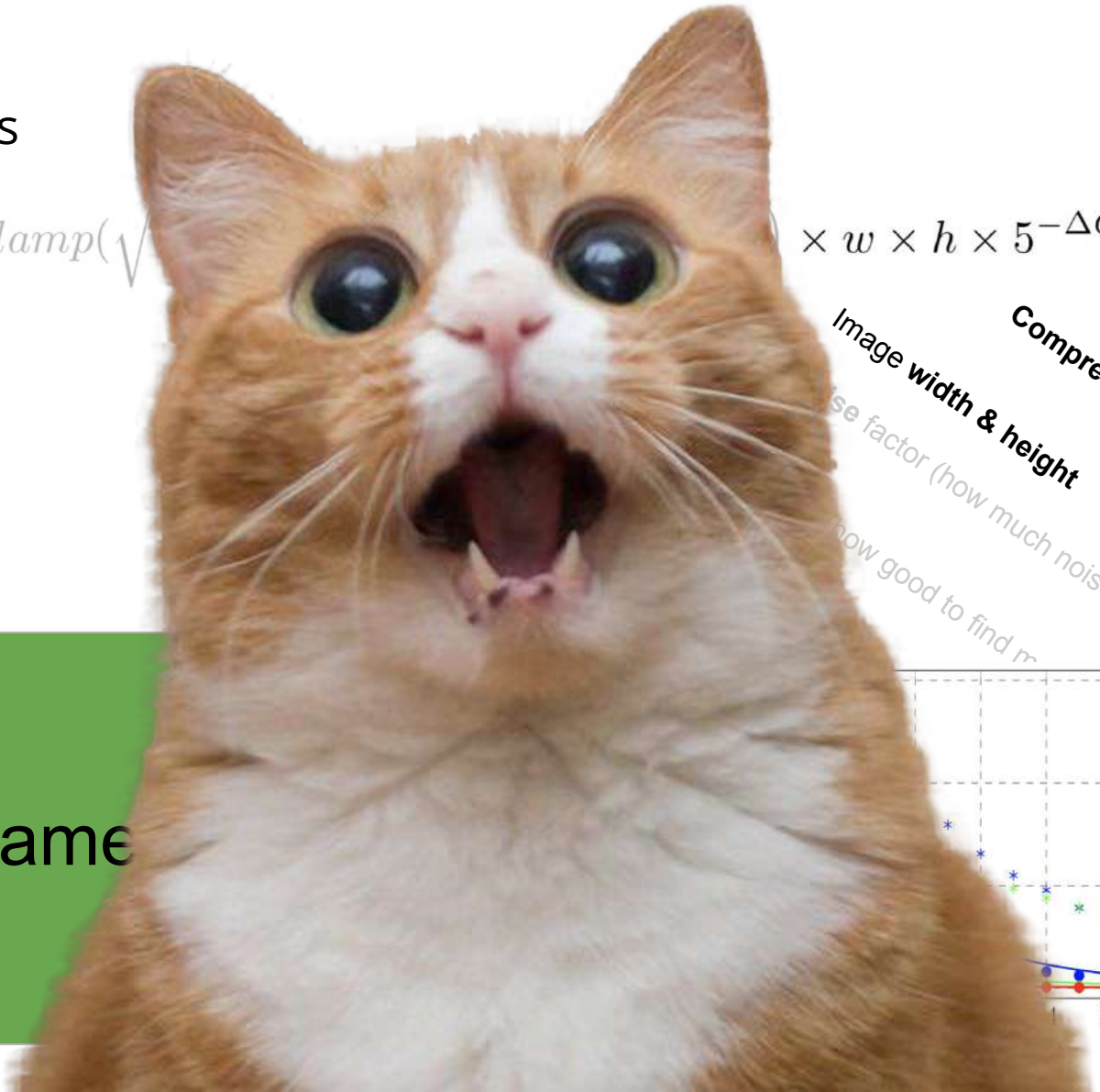
Compression scaling (P-frame)

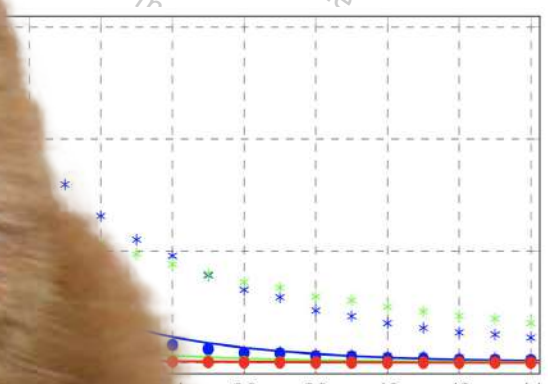
se factor (how much noise from the

ow good to find m

P_C

P-frame





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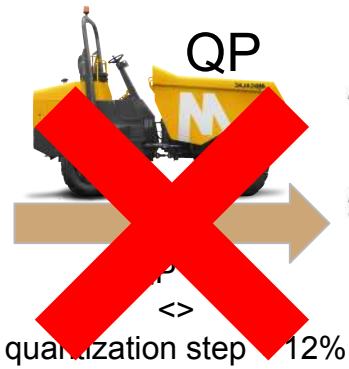

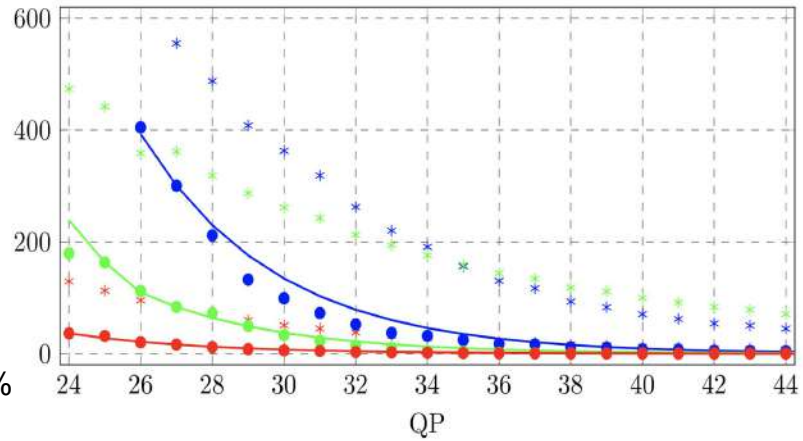

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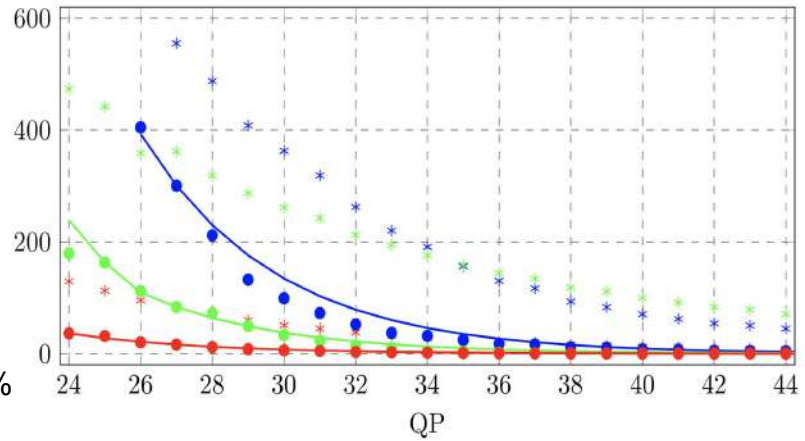

How do we dimension ?

4. Video bandwidth

How do we dimension ?

4. Video bandwidth

$$I = \left(D_S \times L \times D_C \times (1 + N_F) \times DR \times SAO + N_{C,L} \right) \times w \times h \times 2^{-\Delta QP/6}.$$

How do we dimension ?

4. Video bandwidth

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$$F = \frac{I + (GOP - 1) \times P}{GOP}$$

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$$bandwidth = \text{frame sizes} \times \text{video frame rate}.$$

$$B = F \times FPS.$$

How do we dimension ?

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$$B = F \times FPS.$$

What is already out there ?

Two documented algorithms:

- **RQM**: Ding, W. and B. Liu (1996). “Rate control of mpeg video coding and recording by rate-quantization modeling”
- **SOTA**: Seetanadi, G. N., L. Oliveira, L. Almeida, K.-E. Arzen, and M. Maggio (2017). “Game-theoretic network bandwidth distribution for self-adaptive cameras.
- + multiple closed source security industry solutions (H.264?)

RQM (MPEG)

$$s(q_r) = \alpha + \beta \cdot 1 / q_r^{\gamma}$$

s: frame size
q_r: compression level (1..31)
α: constant (overhead bits)
β: constant (resolution & motion)
γ: constant (frametype)

SOTA (MJPEG)

$$s(q_l) = q_l \cdot s_{max}$$

s: frame size
q_l: compression level (0.01..1) ;
s_{max}: "raw" max frame size

How do we perform ?

Bandwidth prediction

Tests

1. Verification of the prediction using recorded material available at Axis communications
2. On-site test in a hotel complex

How do we perform ?

Bandwidth prediction

Relative error %

Scenario		MODEL	SIMP	SOTALIN	SOTAEXP
Parking lot no motion	1	2.88%	12.96%	18102.64%	1853.12%
Parking lot low motion	2	3.70%	9.36%	11731.72%	1169.53%
Parking lot high motion	3	14.49%	26.55%	5815.86%	534.77%
Parking lot no motion	4	1.17%	16.57%	13762.27%	1164.47%
Parking lot low motion	5	8.13%	0.98%	10373.71%	855.38%
Parking lot high motion	6	3.60%	8.43%	6184.23%	473.23%
Highway	7	3.57%	30.76%	1793.07%	103.12%
Highway	8	17.86%	37.51%	6660.98%	625.45%
Fence	9	6.17%	22.18%	1038.00%	133.95%
Fence	10	7.14%	69.19%	247.72%	28.51%
4k street	11	9.48%	157.25%	1984.79%	180.55%
2k fence	12	3.93%	3.03%	14076.62%	1193.15%
Road crossing	13	18.57%	48.22%	5272.21%	354.30%

Scenario numbers come from H.264 Video Frame Size Estimation: http://bit.ly/2LvcWtS

Lower = better

How do we perform ?

Bandwidth prediction

Industrial field test at a hotel complex, against 5 commercial bitrate estimations (obfuscated).

11 scenarios, ~5 days recordings.

Relative error %

	Scenario	MODEL	SIMP	EXT 1	EXT 2	EXT 3	EXT 4	EXT 5
Reception	14	1.48%	7.06%	54.78%	40.92%	134.02%	44.39%	170.03%
Exit door	15	167.48%	806.24%	1678.17%	1518.85%	2588.49%	1558.73%	3002.18%
Office	16	47.67%	255.90%	470.10%	419.02%	761.96%	431.81%	894.59%
Street corner	17	10.91%	81.79%	106.88%	88.34%	212.79%	92.98%	260.92%
Reception	18	75.24%	104.66%	169.61%	145.46%	307.64%	151.50%	370.37%
Mall	19	51.40%	9.14%	84.40%	67.88%	178.81%	72.02%	221.71%
Elevator	20	11.37%	70.20%	50.19%	36.74%	127.08%	40.10%	162.02%
Exit door	21	207.49%	745.77%	1254.80%	1133.41%	1948.37%	1163.79%	2263.57%
Parking lot	22	9.56%	15.40%	51.00%	70.22%	82.89%	83.87%	83.17%
Parking lot	23	17.33%	49.91%	62.27%	47.73%	145.35%	51.37%	183.10%
Parking lot	24	17.43%	15.22%	105.64%	131.82%	149.07%	150.42%	149.46%

Scenario numbers come from H.264 Video Frame Size Estimation: http://bit.ly/2LvcWtS

Lower = better

How do we perform ?

Bandwidth prediction

Average relative errors

Our model: 29%

SOTA: 2100%

Commercial models: 336%

How do we perform ?

Scheduling prediction

Tests

1. Verification using recorded material with triggered motion amount

How do we perform ?

Low Motion

Scheduling prediction

I part of the frame P part of the frame

How do we perform ?

Low Motion

Scheduling prediction

How do we perform ?

High Motion

Scheduling prediction

I part of the frame P part of the frame

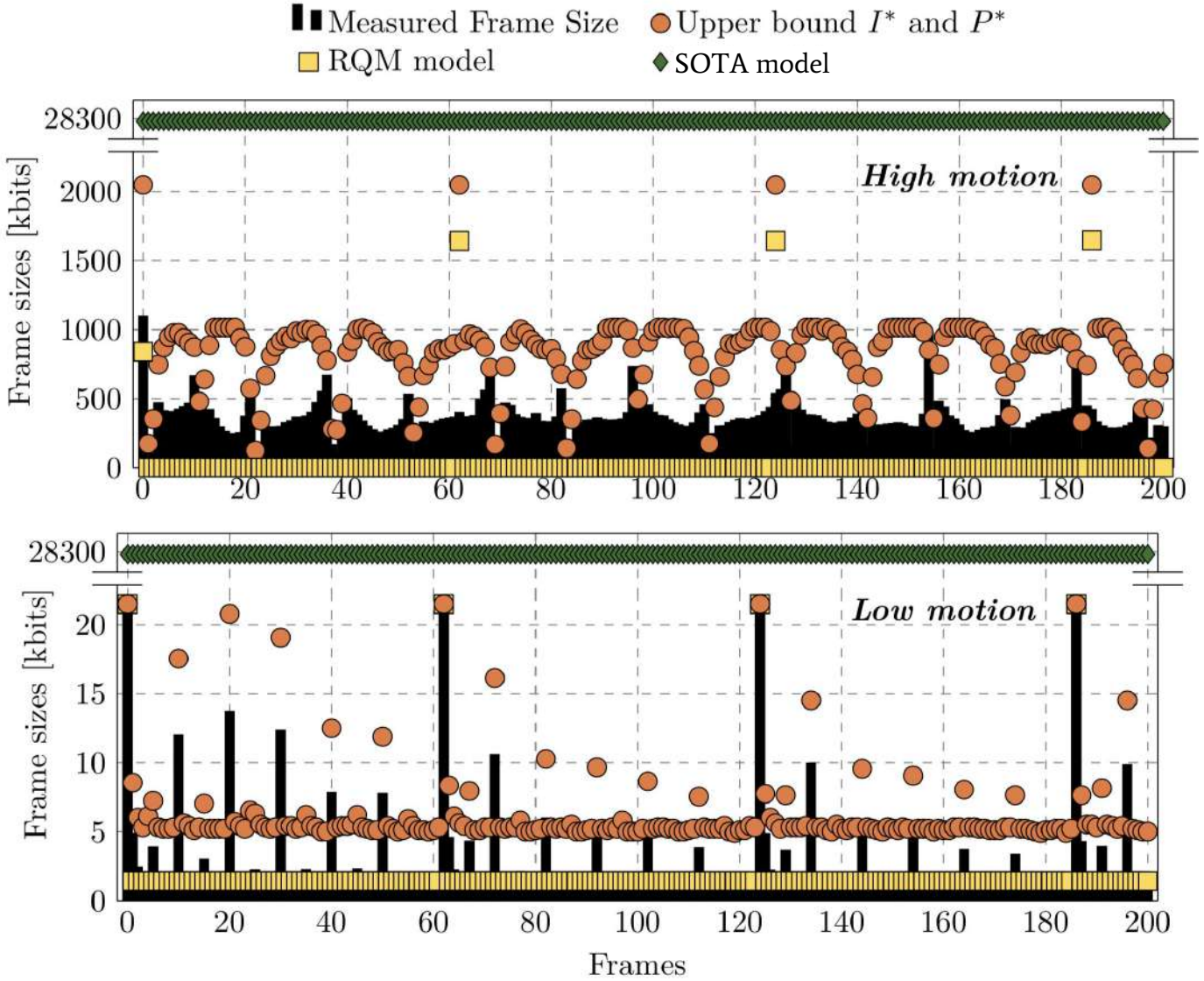
How do we perform ?

High Motion

Scheduling prediction

How do we perform ?

Scheduling prediction



How do we perform ?

Scheduling prediction

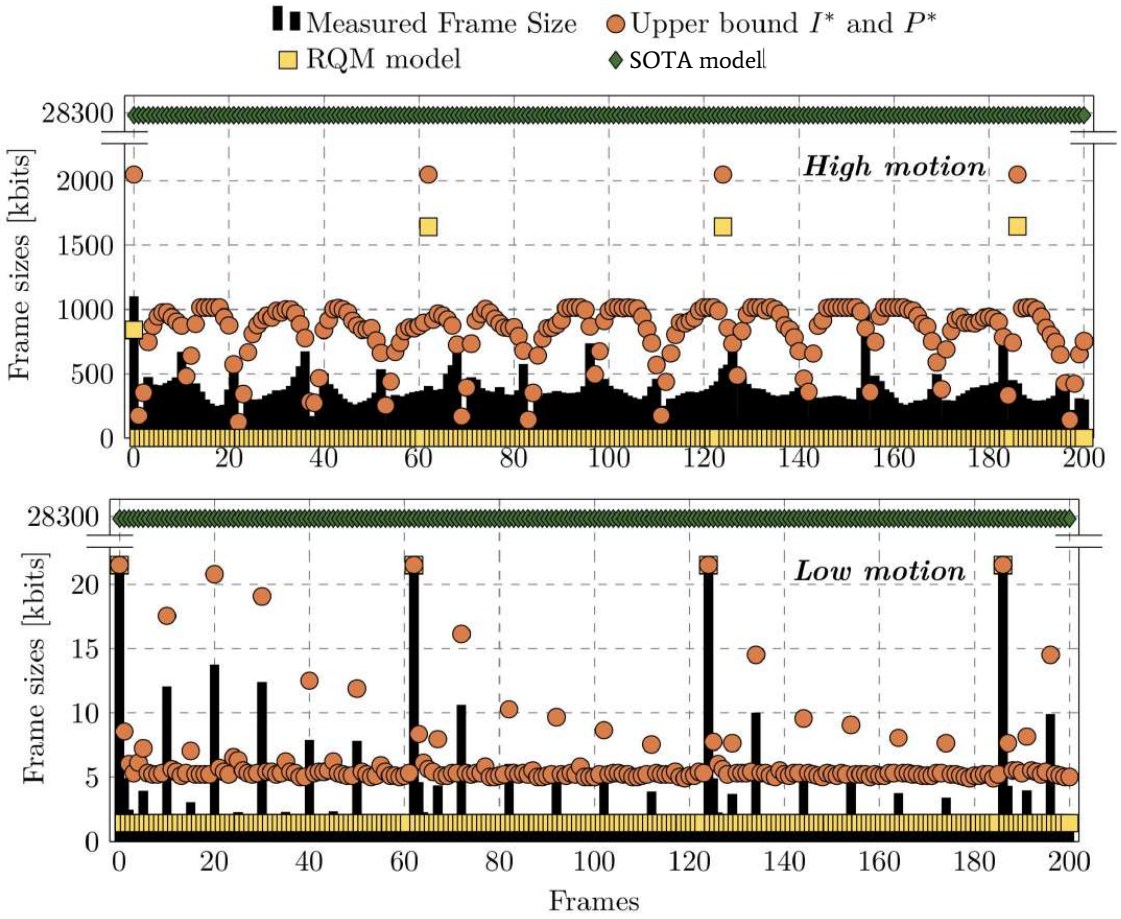
RQM performs sometimes better

... but is a posteriori

... underestimates sometimes

SOTA over-estimates A LOT

(as expected)



Take away

- Model set of cameras with a taskset model.
  - allow reuse scheduling results from multiframe model.
  - better model for worst case transmission time.
  - simple enough to be run on camera.

- Perform better (by a magnitude) than competitors.
  - both academic and industrial.
  - tested in real life scenario.
  - deployed and running for year(s).

QUESTIONS ?

REMARKS ?

KEEP
CALM
AND
Don't Shoot the
Messenger

Did you find the cookie monster ?

Thank you !

http://bit.ly/2HtAVrb

alexandre.martins@axis.com

gitlab.com/MaralAfris

/in/martinsalexandre

Did you find the cookie monster ?