Lecture 17:

Image Processing Architectures (and their future requirements)

Visual Computing Systems
CMU 15-869, Fall 2013

Smart phone processing resources

Qualcomm snapdragon

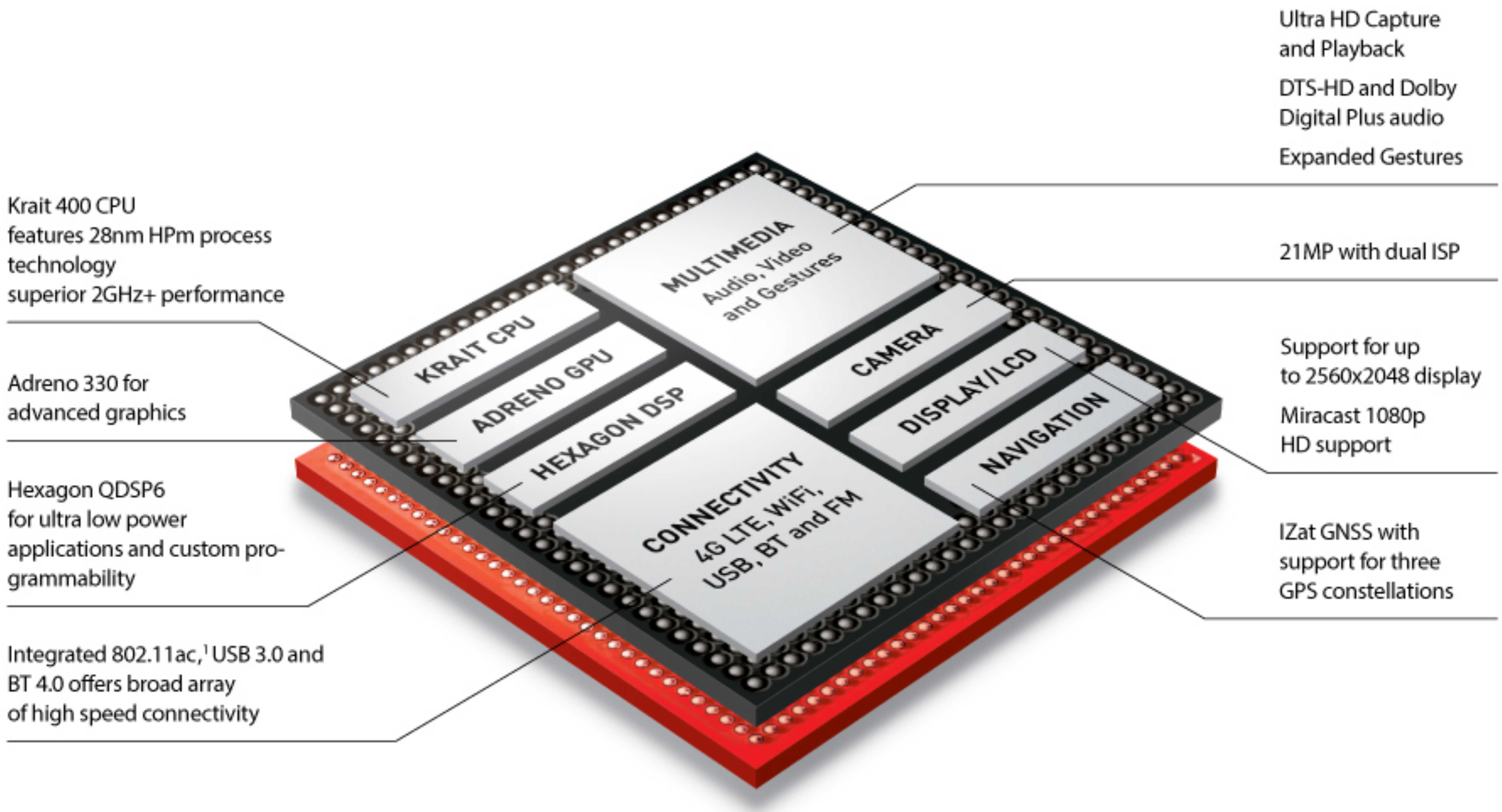
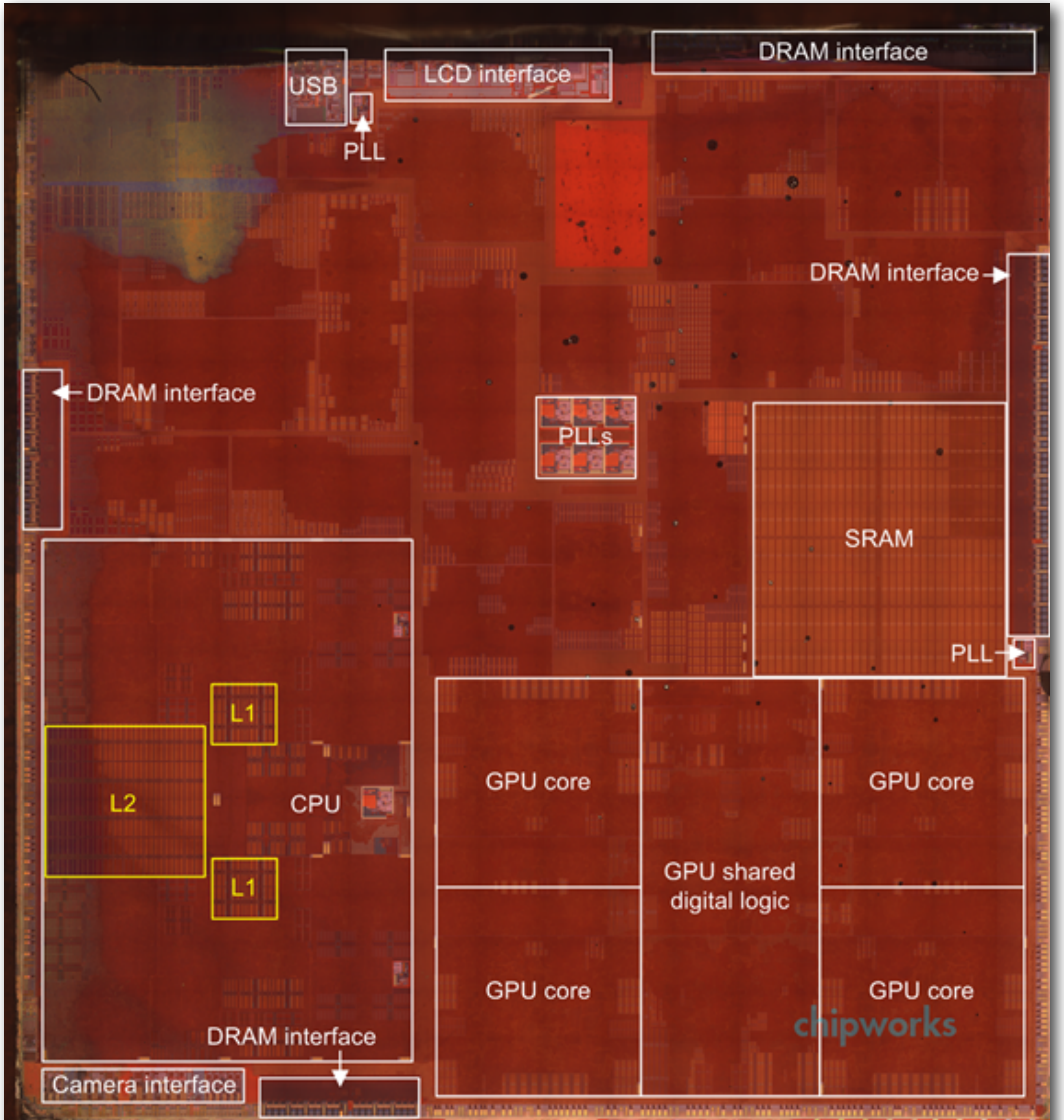


Image credit: Qualcomm

Apple A7 (iPhone 5s)



Dual-core ARM ~ Imagination PowerVR Series 6 (G6430)

- **Chipworks estimates:**
  - CPU + cache: 17% area
  - GPU: 22% area

    (Imagination PowerVR Series 6 (G6430))
  - Big SRAM block above GPU: 3-4 MB?

Source: http://www.chipworks.com/en/technical-competitive-analysis/resources/blog/inside-the-a7/

Discussion

- Traditional rule of thumb in system design is to design simple, general-purpose components. This is not the case with mobile processing systems (perf/watt)

- Needs of high bandwidth sensing and media processing are a big part of these designs [image/video/audio processing, 2D/3D graphics]
  - User interfaces are visually rich
  - Games
  - Speech recognition
  - Photography/video
    - Acquire signal, compute images (not directly measuring an image)
    - More processing --> smarter sensing
    - More processing --> more flexibility?

- Questions for architects:
  - Re-homogenize, or become increasingly heterogeneous?
  - How does an application developer think about these systems?

Frankencamera

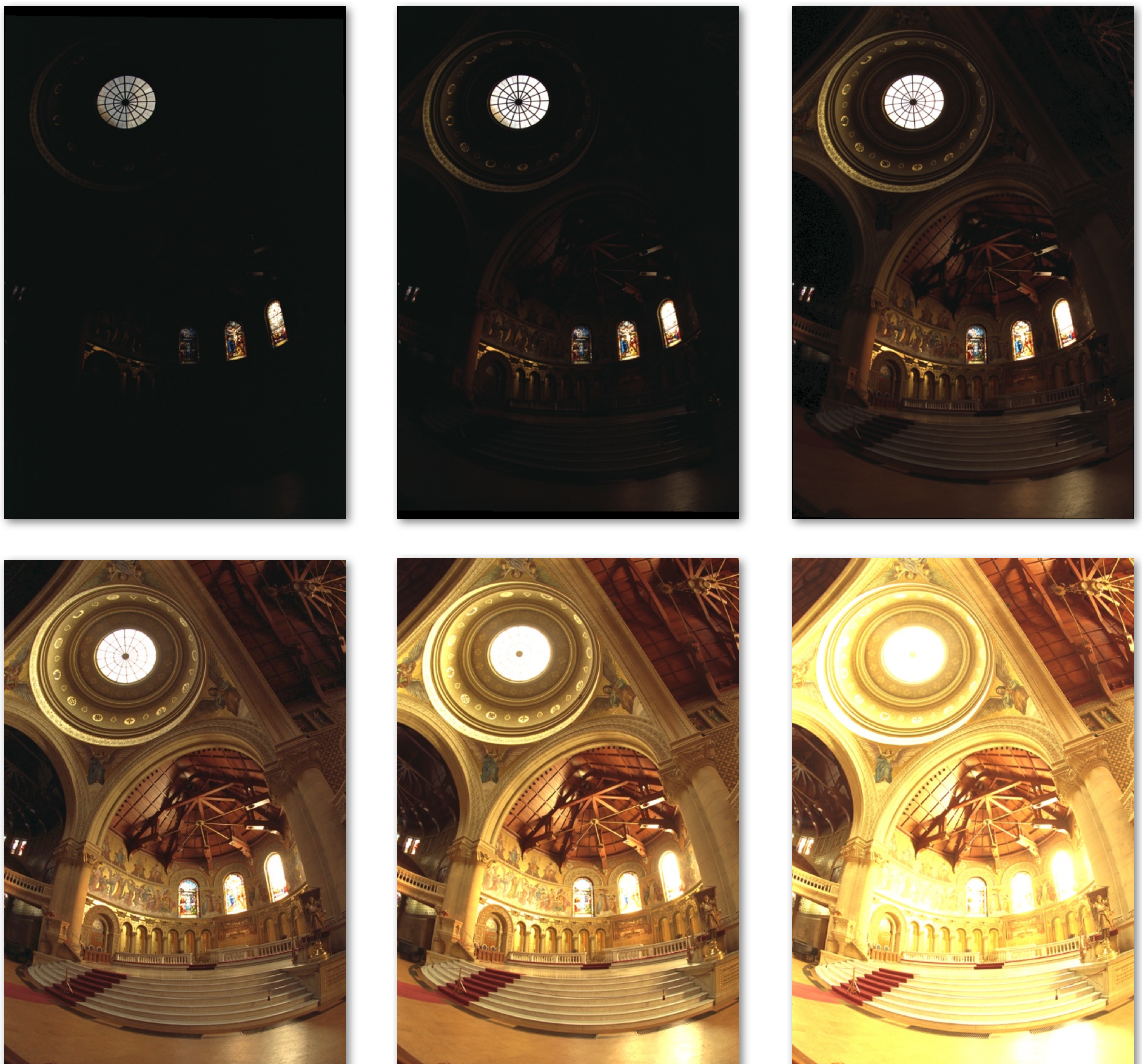
Frankencamera context

- Cameras are cheap and ubiquitous
- Significant processing capability on cameras
- Many techniques for combining multiple photos to overcome deficiencies in traditional camera systems

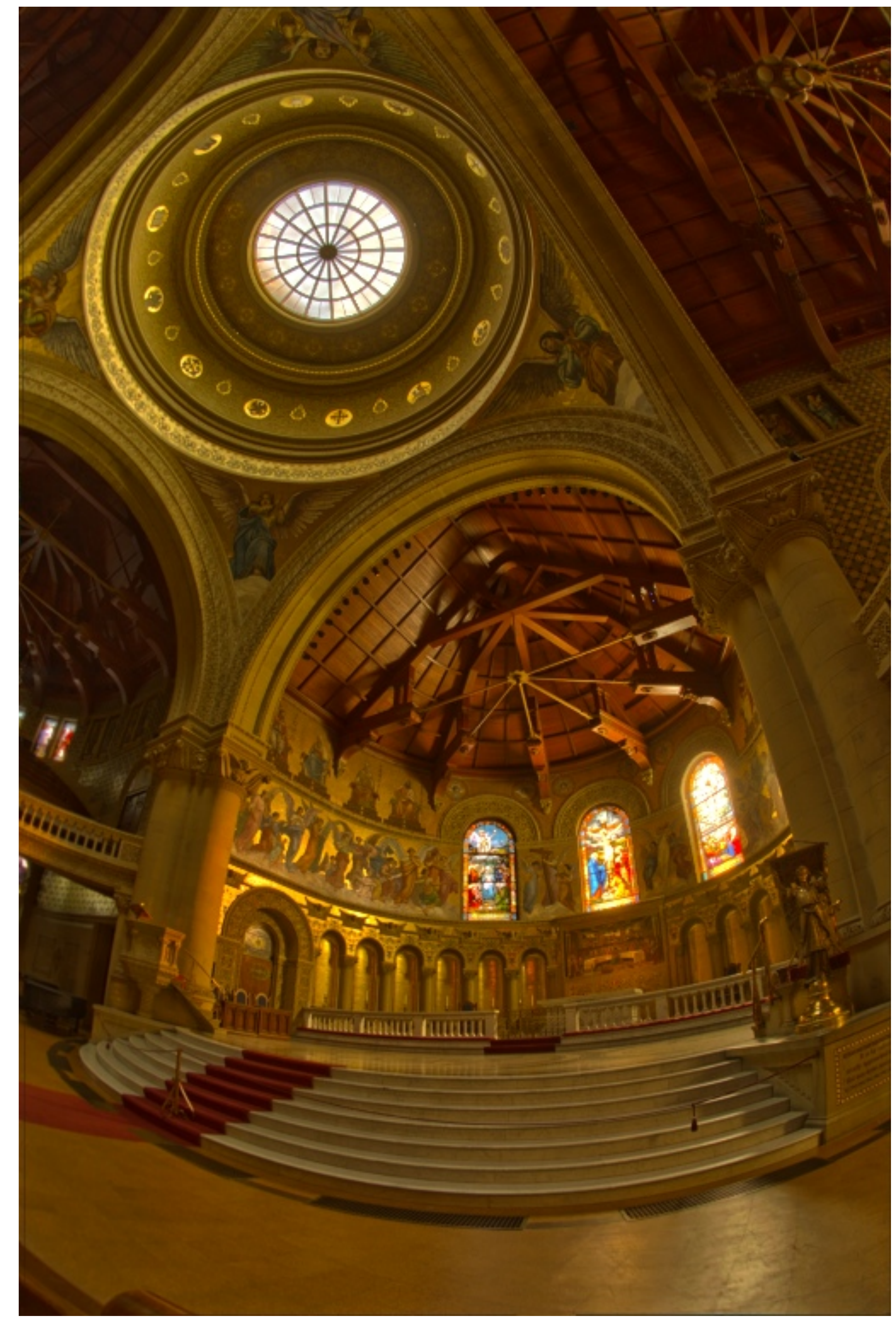
- But… ability to implement techniques on cameras was limited
  - Cameras not programmable by general public
  - Where some programmability did exist, interface too basic

    (end result was that latency between two photos was high, mitigating utility of multi-shot techniques)

Example: high dynamic range images



Source photographs: varying exposure



Tone mapped HDR image

Credit: Debevec and Malik

More multi-shot photography examples

"Lucky" imaging

Take several photos in rapid succession: likely to find one without camera shake

Flash-no-flash photography [Eisemann and Durand]
(use flash image for sharp, colored image, infer actual room lighting from no-flash image)

Frankencamera goals

[Adams et al. 2010]

1. **Create open, handheld camera platform for researchers**

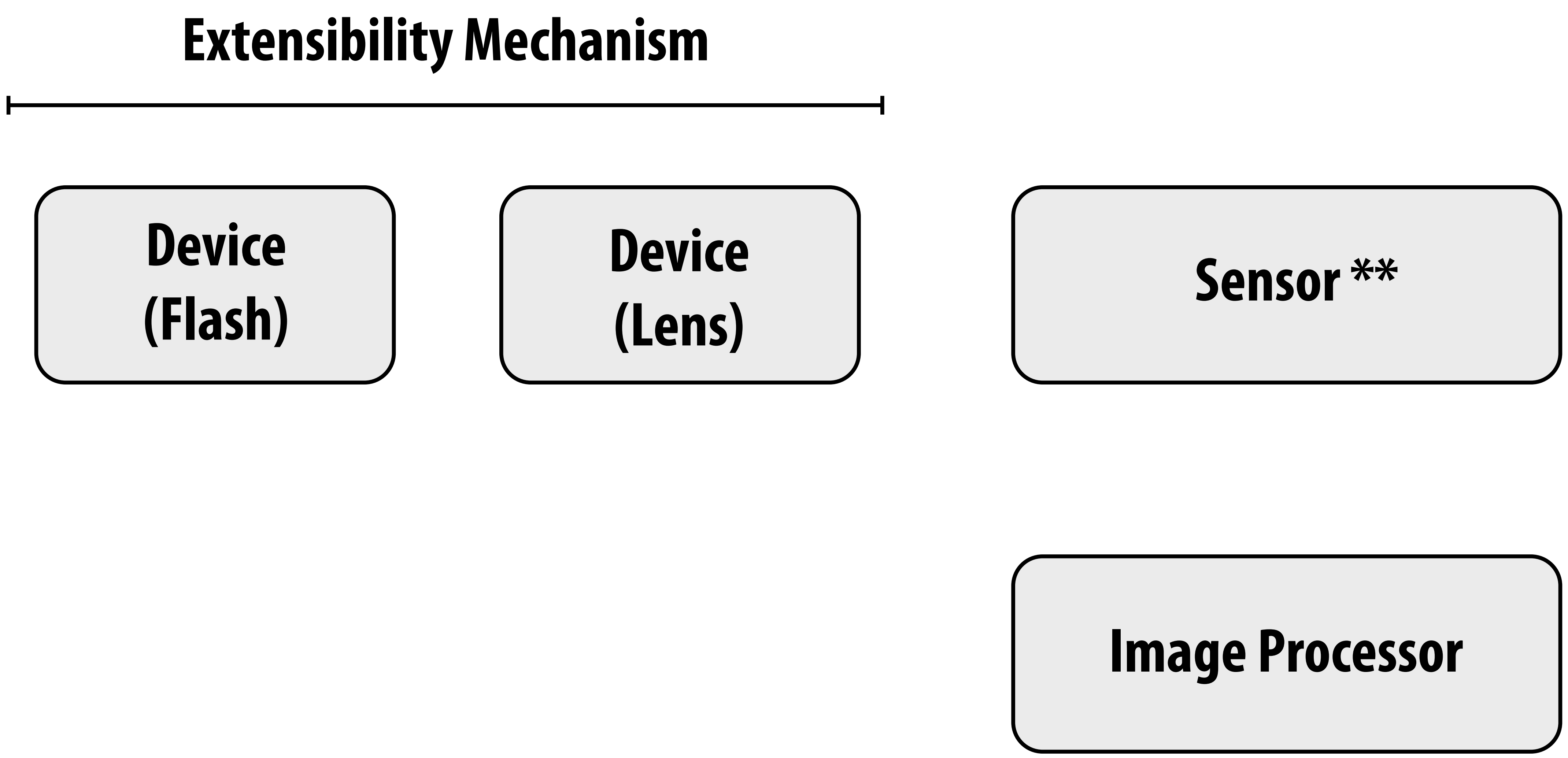
2. **Define system architecture for computational photography applications**
   - **Motivated by impact of OpenGL on graphics application and graphics hardware development (portable apps despite highly optimized GPU implementations)**
   - **Motivated by proliferation of smart-phone apps**

F2 Reference Implementation

Note: Apple was not involved in Frankencamera's industrial design. ;-)

Nokia N900 Smartphone Implementation

F-cam components



** Sensor is really just a special case of a device

Shot

- **A shot is a command**
  - Actually it's a set of commands
  - Encapsulates both "set state" and "perform action(s)" commands
- **Defines state (configuration) for:**
  - Sensor
  - Image processor
  - Relevant devices
- **Defines a timeline of actions**
  - Exactly one sensor action: expose
  - Optional actions for devices
  - Note: timeline extends beyond length of exposure ("frame time")

Shot

- **Interesting analogy:**
  - An F-cam shot is very similar to an OpenGL display list
  - A shot is really a series of commands (both action commands and state manipulation commands)
    - State manipulation commands specify the <u>entire state</u> of the system
    - Defines precise timing of the commands (no OpenGL analogy for this)

Frame

- **A frame describes the <u>result</u> of a shot**

- **A frame contains:**
  - Reference to corresponding image buffer
  - Statistics for image (computed by image processor)
  - Shot configuration data (what was specified by app)
  - Actual configuration data (configuration actually used when acquiring image)

Question

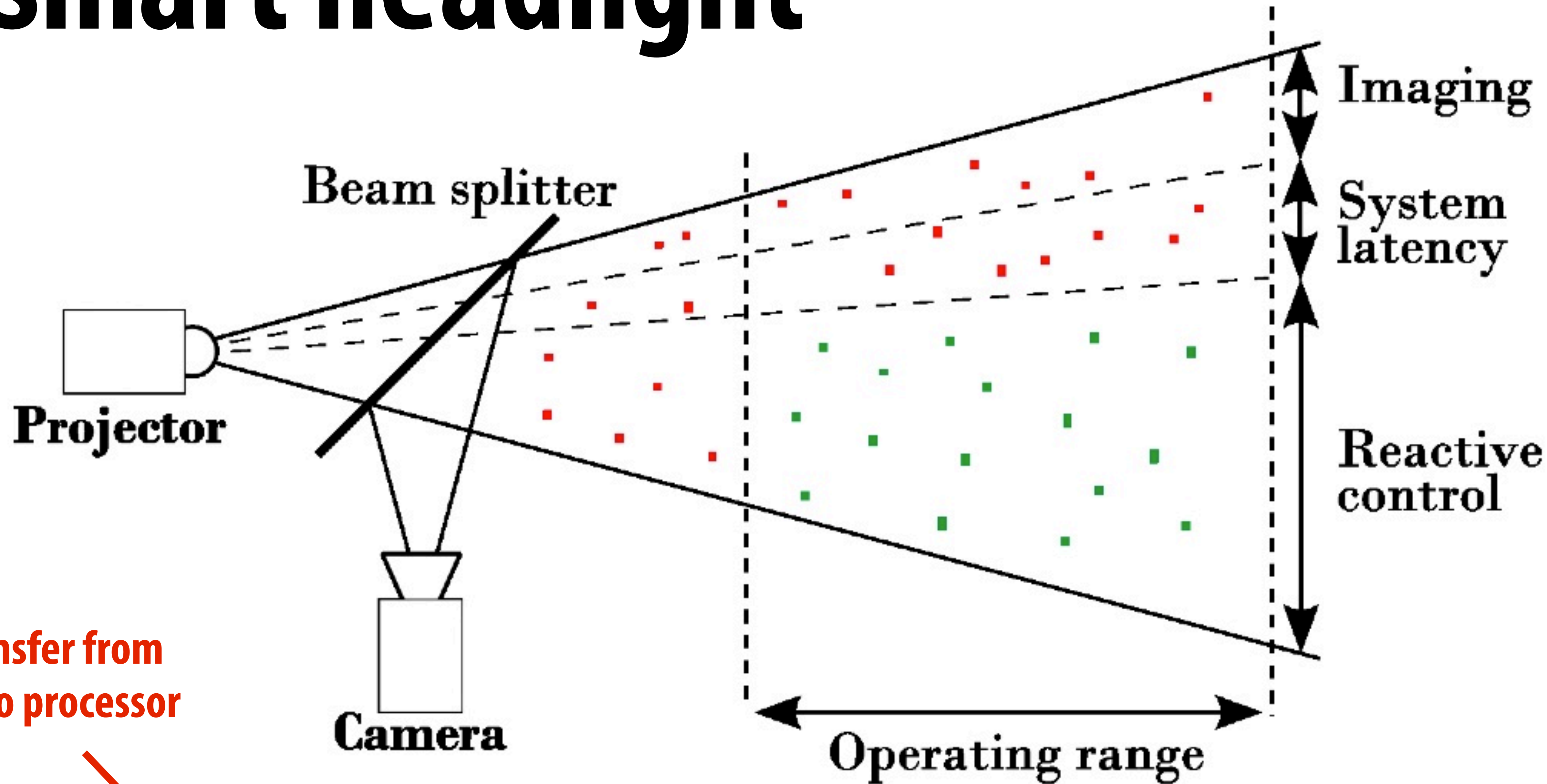
- **What problem in conventional camera interface designs does F-cam address: throughput or latency?**

Aside: latency in camera systems

- Often in this class our focus is on achieving high throughput
  - Triangles per clock
  - Pixel per clock
- But low latency is critical in many visual computing domains
  - Camera metering, focus
  - Optical flow, tracking

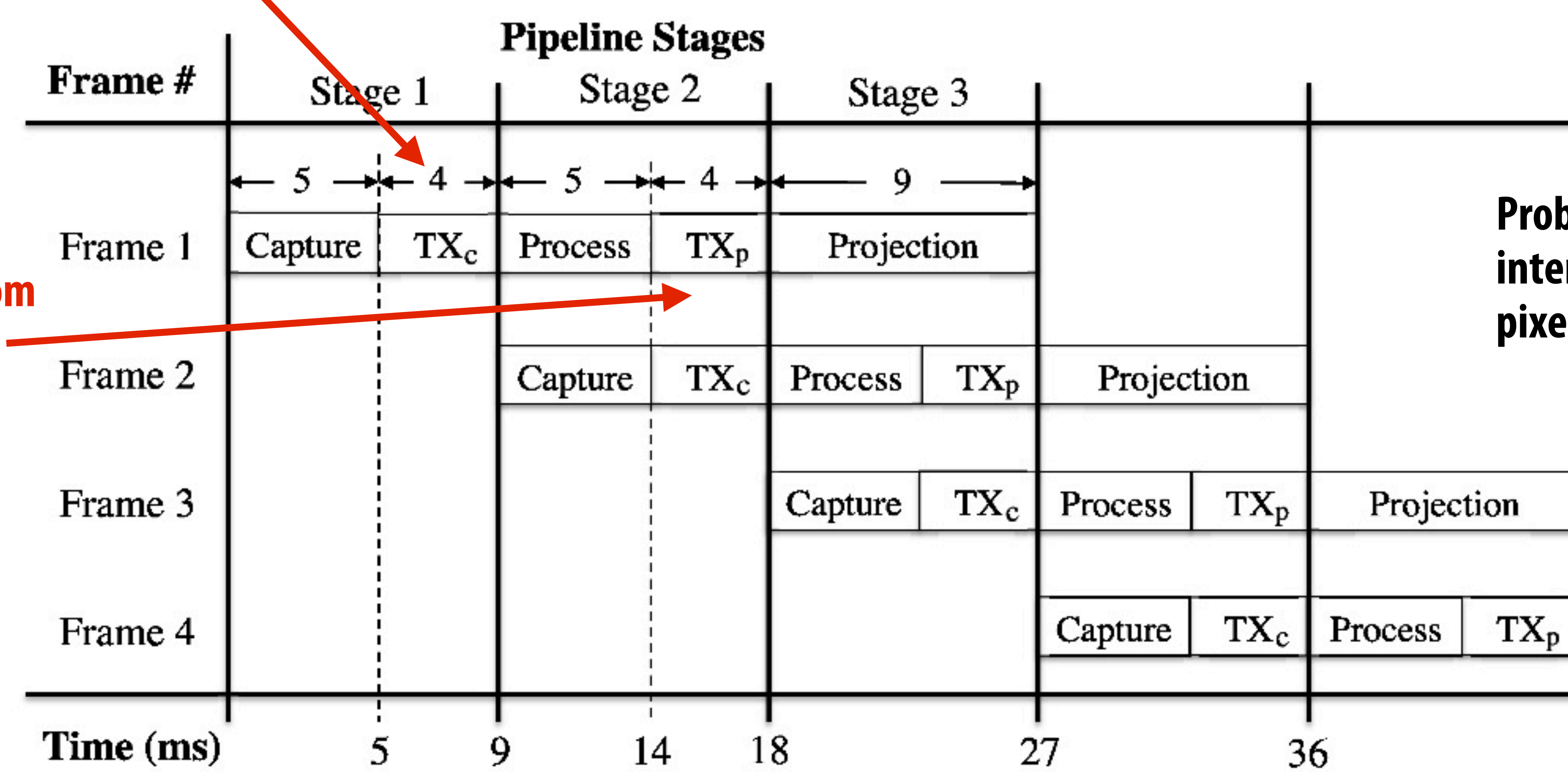
Example:
CMU smart headlight project
[Charette et al. 2012]

CMU smart headlight



data transfer from sensor to processor

data transfer from processor to projector

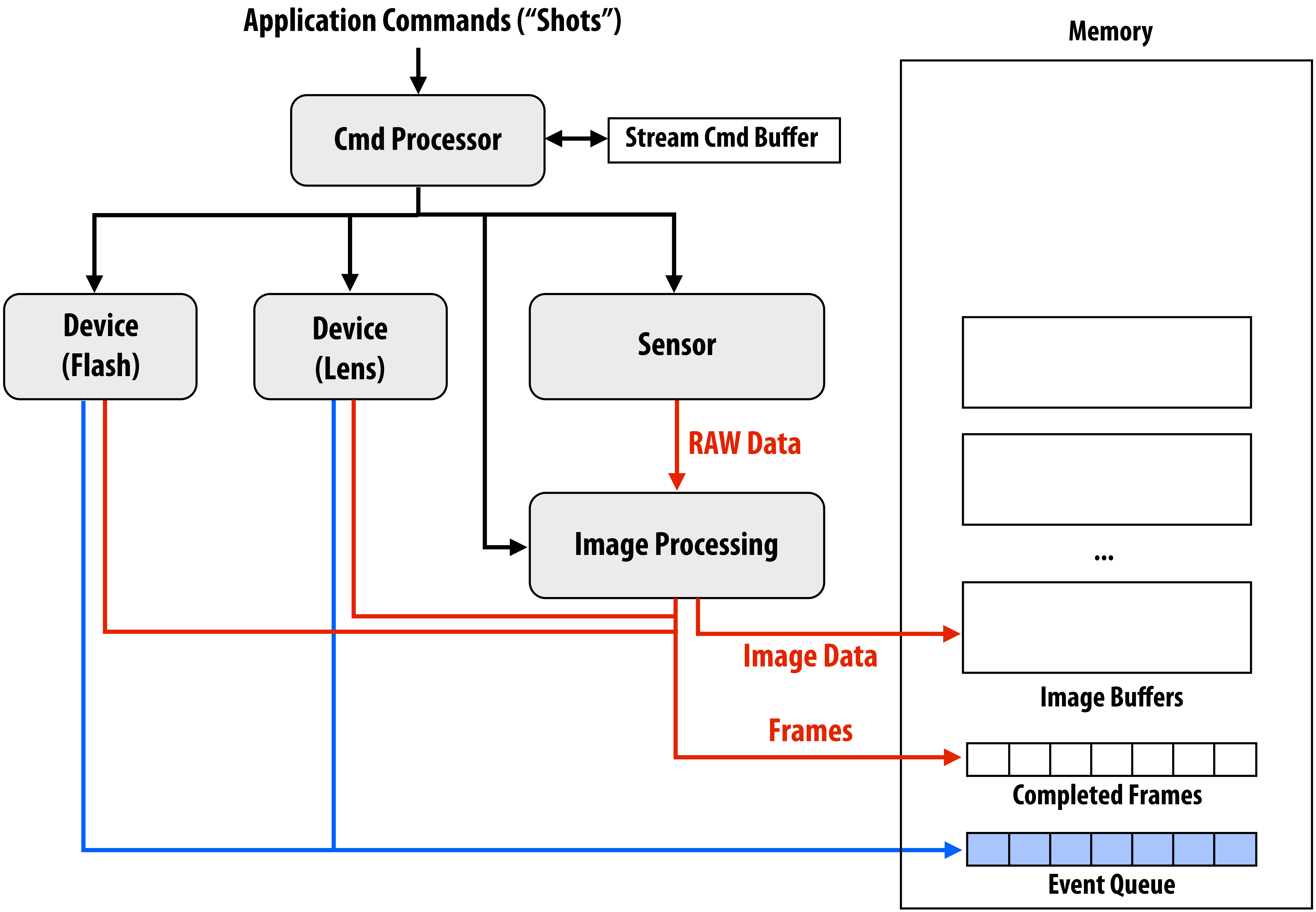


Problem: current sensor, projector interfaces operate at frame (not pixel or pixel row) granularity.

F-cam "streaming" mode

- System repeats shot (or series of shots) in infinite loop
- Stops only when application says so
- Intended for "live view" (digital viewfinder) or metering mode

F-cam as an architecture



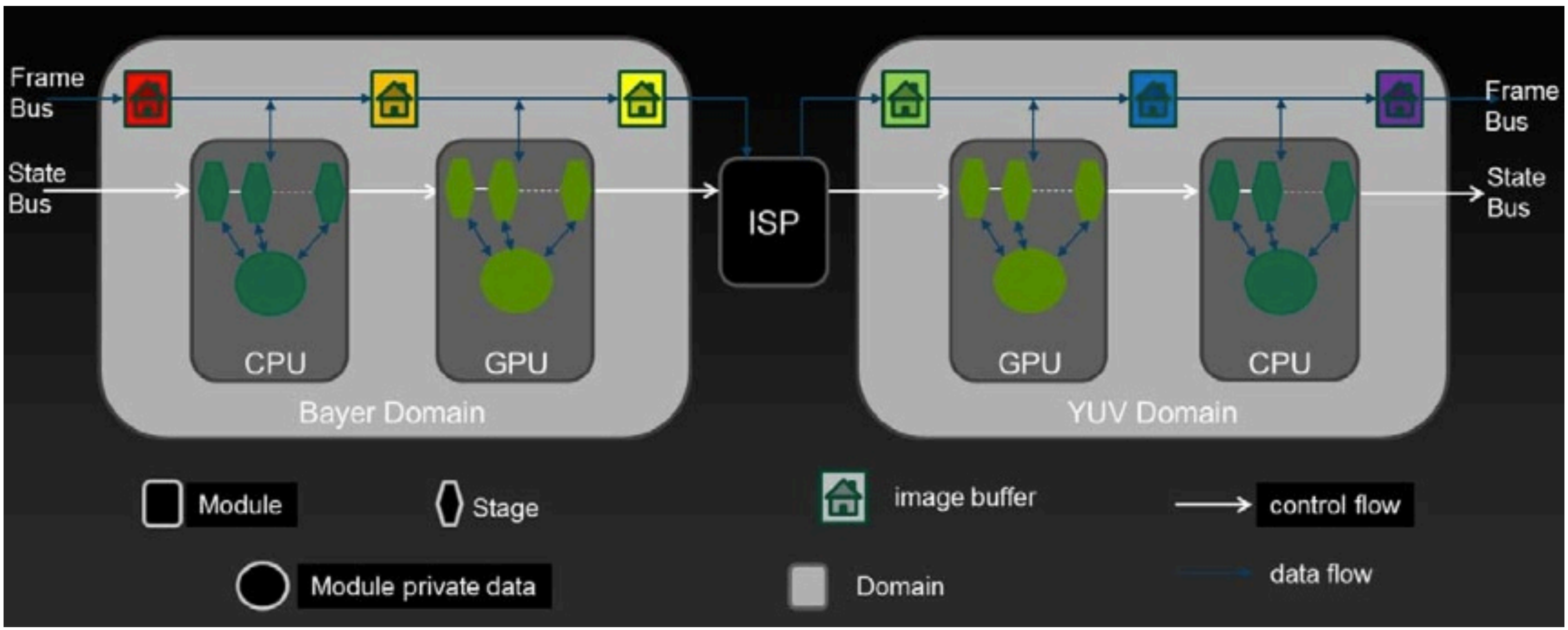
F-cam scope

- F-cam provides a set of abstractions that allow for manipulating configurable camera components
  - Timeline based specification of actions
  - Feed-forward: no feedback loops

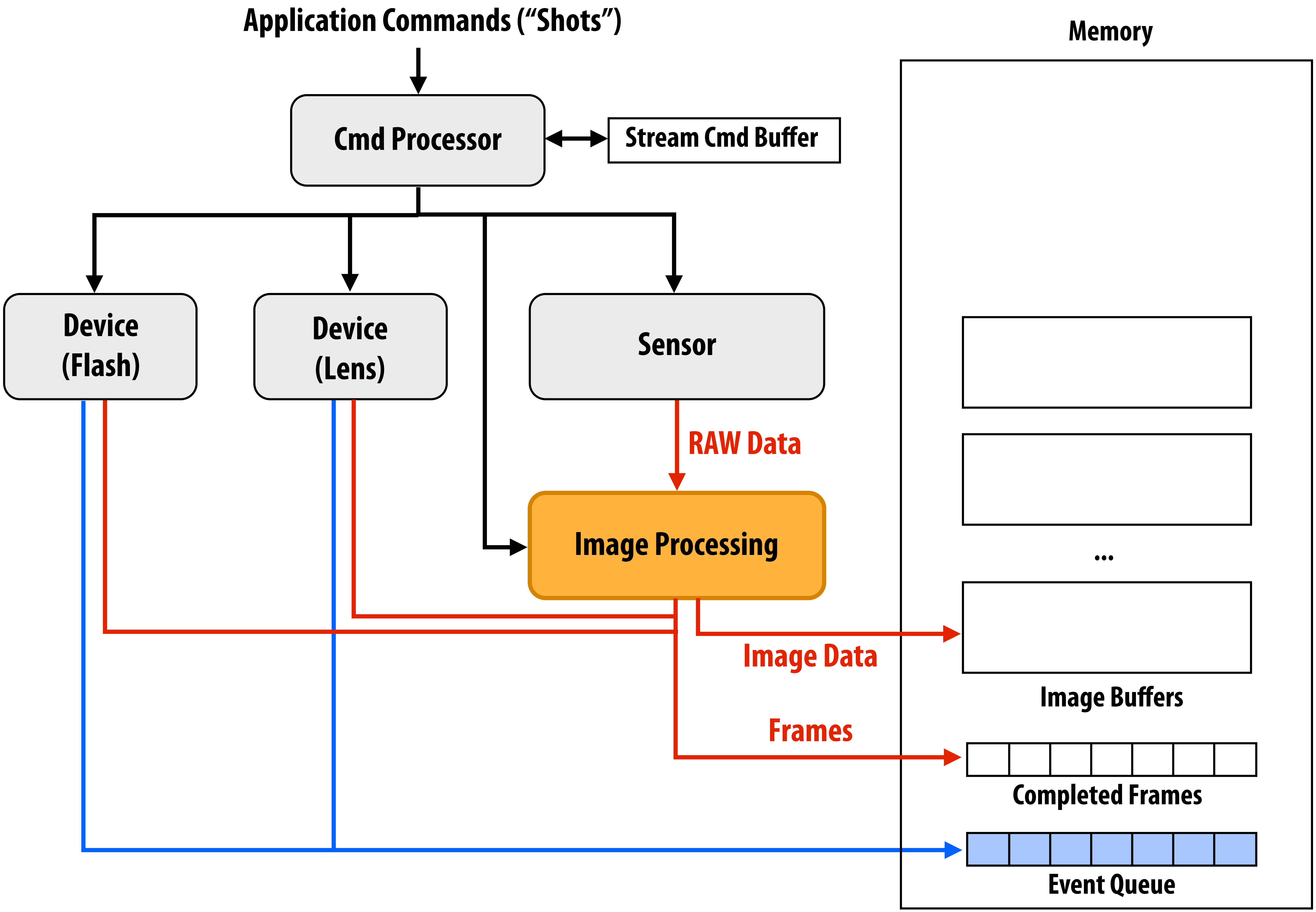
- F-cam architecture performs image processing, but...
  - This functionality is not programmable
  - F-cam does not provide an image processing language
  - Other than work performed by the image processing stage, F-cam applications do all their own image processing (e.g., on smartphone/ camera's CPU or GPU resources)

NVIDIA Chimera

- Software framework for writing computational photography pipelines
- Idea: application provides kernel functions for CPU, GPU (or specifies how to configure/use the ISP) and describes how to connect up the kernels



F-cam extension: programmable image processing



Class design challenge 1

- If there was a programmable image processor, application would probably seek to use it for more than just on data coming off sensor

- E.g., HDR imaging app

Class design challenge 2

- **Question: How does auto-focus work in F-cam?**

- **How might we extend the F-cam architecture to model a separate autofocus/metering sensor?**

Class design challenge 3

- Should we add a face detection unit to the architecture?
- How might we abstract a face detection unit?
- Or a feature extractor?

Architecture is hard.

Discussion

- **Is there a need for a camera "App Store"?**