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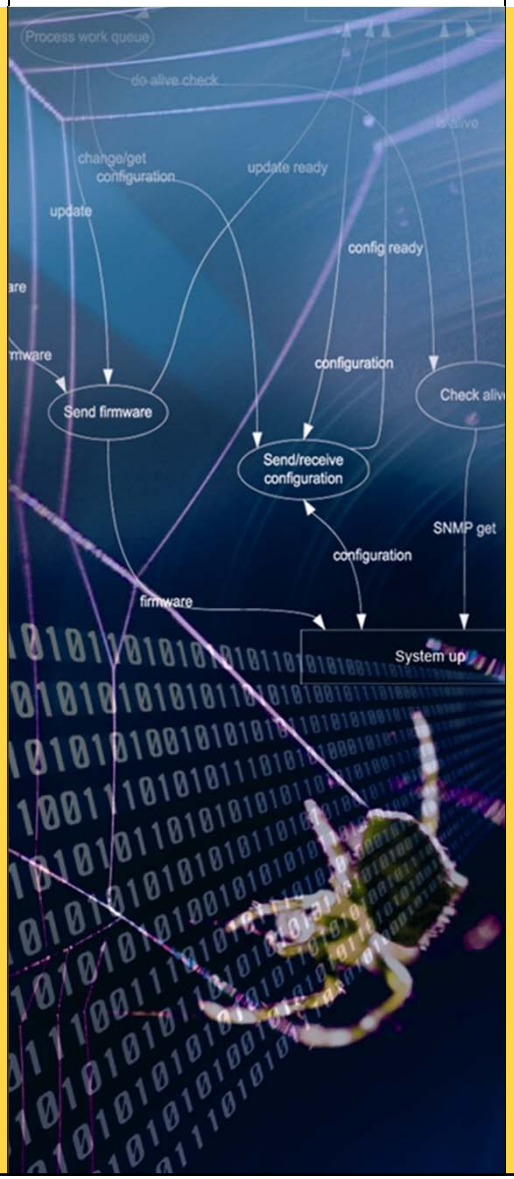

/Agile techniques applied to system design to mitigate engineering uncertainty

Dave Marples
Marc van Eert

>the right development

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/overview

* The challenge
* Principle of direct electron microscopy
* Starting point for the project
* Specialism required and key concerns
* Use of the agile approach
* Key challenges in each subsystem
* The result
* Learnings from the use of an agile methodology
* Conclusions and Next steps

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/the challenge

To research, design and document for production a novel Transmission Electron Microscope (TEM) camera assembly exploiting direct electron excitation using poorly characterized, highly innovative, critical components.

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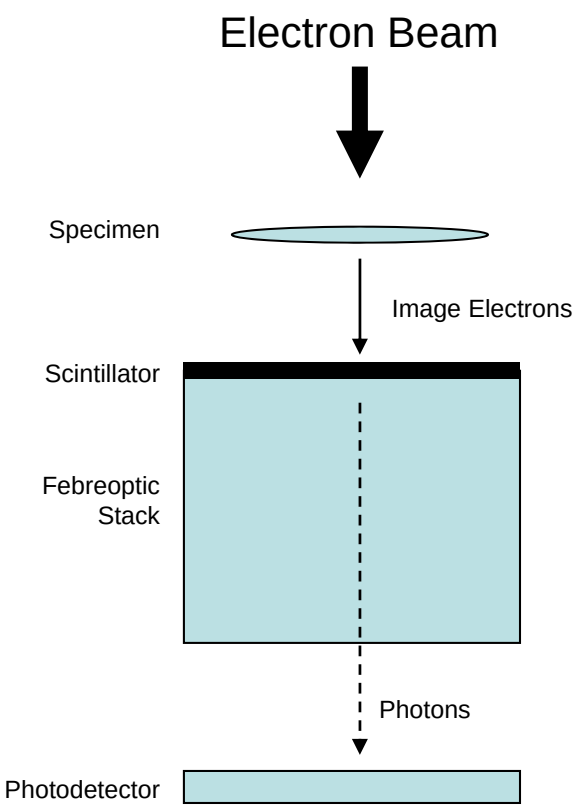
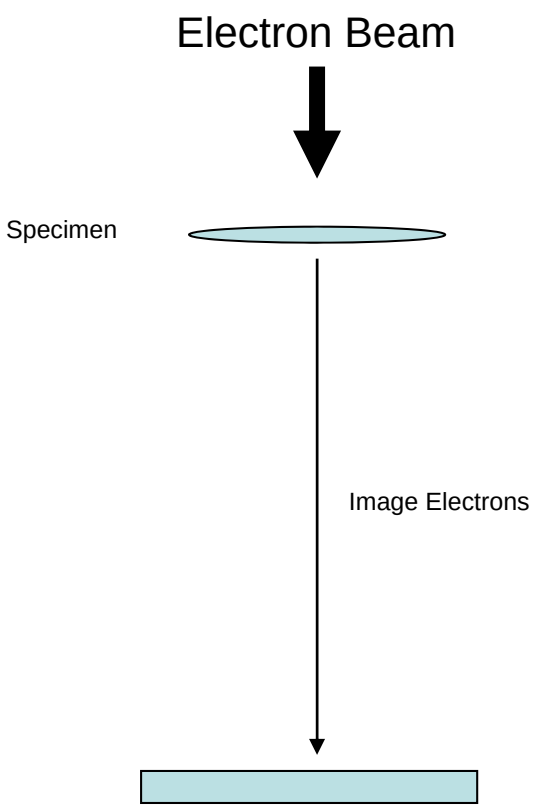
/key novelty





Direct Electron excitation provides a cleaner image path, leading to better images

It also requires less electrons, leading to less specimen deterioration.

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/starting point

* A 4k x 4k CMOS direct electron imaging sensor had been commissioned and proven to operate in a test environment.

* No detailed performance characterisation data had been determined for the sensor.

* Numerous design optimisations of the sensor meant that specific electrical considerations had to be made to accommodate it.

* It was unclear exactly what temperatures the sensor could be configured to operate at and what other operational restrictions would be required.

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/specialism required

* **mechanical design:** the sensor needs to be housed in a module with very specific size, tight tolerance, cooling, stringent vacuum and radiation constraints
* **electronics:** the sensor needs to be interfaced to as an analogue domain component
* **programmable logic:** The speed of image acquisition demands hardware rather than software techniques
* **software:** the camera needs to be controlled via software systems, and higher level image processing is performed via soft functionality
* **systems engineering:** everything needs to come together and be delivered as a working system.

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/specific physical concerns

* mechanical issues;
  * tolerances
  * cooling and dissipation
  * motion
  * space availability
* vacuum techniques;
  * leaching
  * component performance
  * crossing
* lifetime issues;
  * 1 000 000 movement cycles
  * 1000 thermal cycles
* human safety;
  * X-ray
* image quality;
  * system noise and image quality
* operational safety;
  * failure modes and power loss handling
  * interlocks to prevent component (esp. sensor) damage

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/specific electronic concerns

* image quality;
  * system noise and image quality
* speed;
  * high frame rate at 16Mpixel
* drivers;
  * uncertain voltages and currents for analogue components
* extremely limited space.

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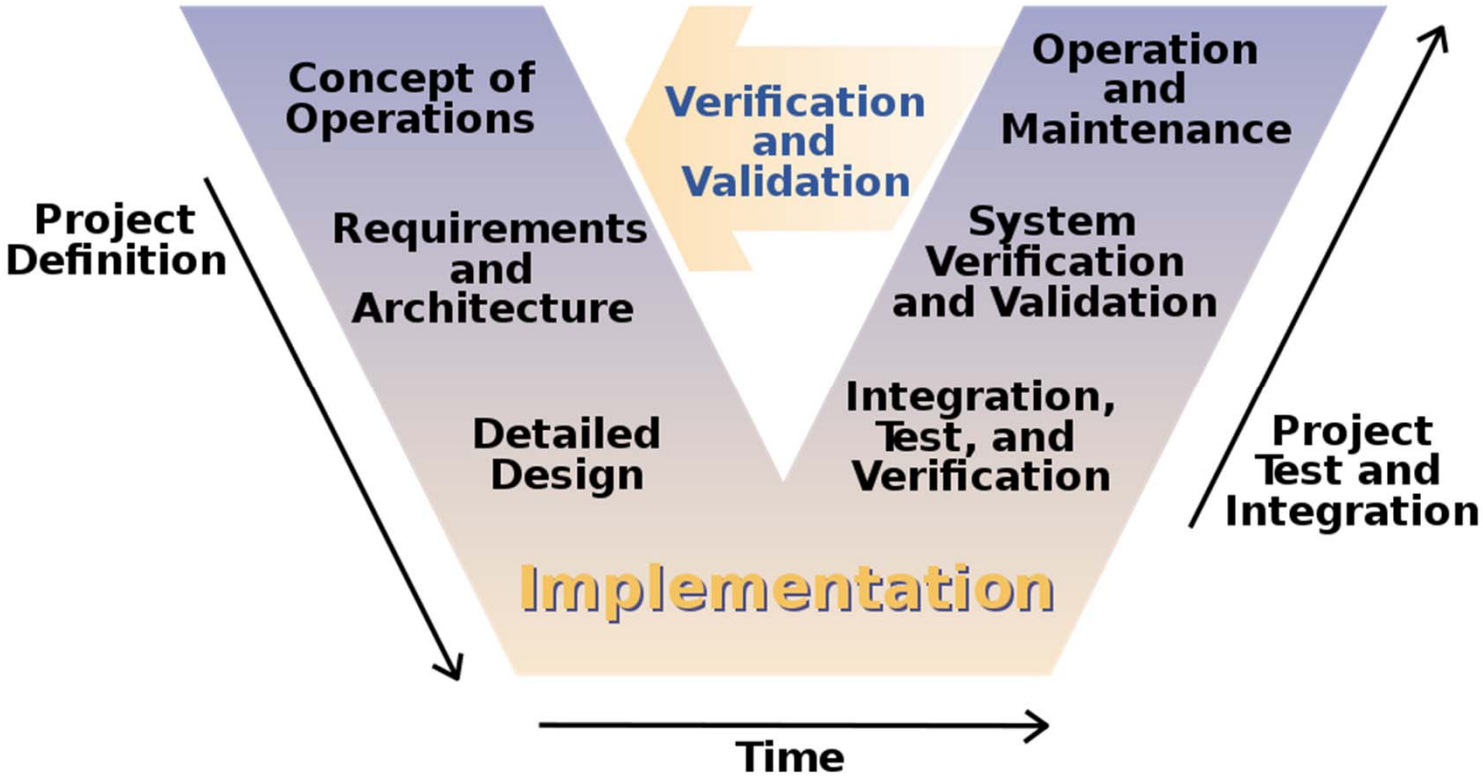
/traditional approach



Source: FHWA-JPO-05-072, Federal Highway Administration (FHWA), 2005 via Wikipedia

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/the agile manifesto

We are uncovering better ways of developing software by doing it and helping others do it.

Through this work we have come to value:

- **Individuals and interactions** over processes and tools
- **Working software** over comprehensive documentation
- **Customer collaboration** over contract negotiation
- **Responding to change** over following a plan

That is, while there is value in the items on the right, we value the items on the left more.

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/the chosen approach

* Adapt the agile software development manefesto;
  * **Individuals and Interactions** → Communication and collaboration, work to convergence
  * **Customer collaboration** → Early and continuous visibility, working with the commercial teams
  * **Responding to change** → Accommodate changing requirements and component specifications
  * **Working 'Software'** → Working subsystems, simplified and partitioned for flexibility
* Keep the customer **closely** involved, avoid surprises → open communications
* Blend the research, development and production phases

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/agile tactics

* Elements specific to this project;
  * Customer in the loop
  * Short development cycles (sprints, timeboxes)
  * Adaptive requirements
  * Flexible design elements

* Elements from our core business
  * Co-location and bullpens
  * Motivated individuals and devolved responsibility
  * Tecexcelence
  * Self Organising Teams
  * Adaptation to changing circumstances

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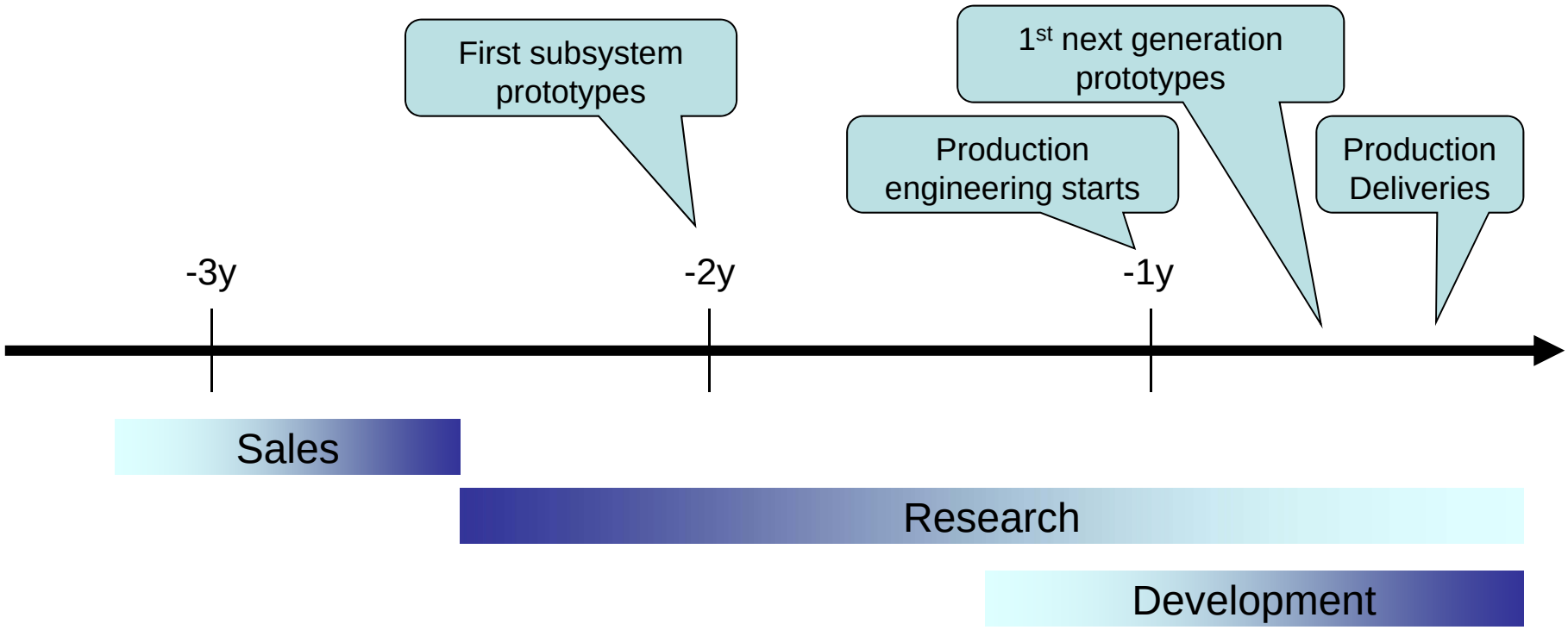
/timeline



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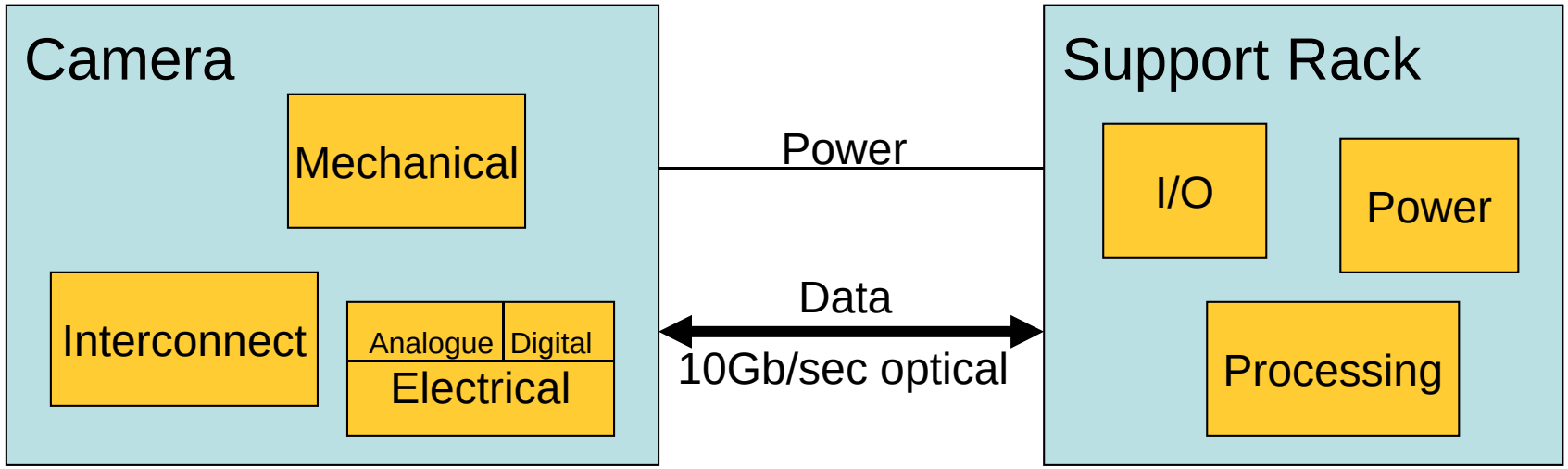
/subsystem partitioning



Just like software;

- Maximise intra-subsystem coupling
- Minimise inter-subsystem coupling

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/camera mechanics

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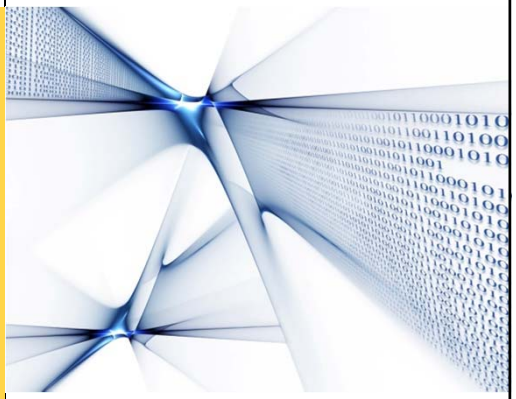
/issues around mechanical design



* Ribbon connector – 1M cycle move requirement, 300 tracks through vacuum bulkhead to BGA connector
* PCB as vacuum seal component
  * Leach free requirement
  * Blind and buried vias
  * Direct ultrasonic bonding of sensor to PCB
* Size constraints
  * sensor 62mm^2 with requirement for line drivers in 75mm^2 space
* Need to cool using 8 Peltier coolers
* X-Ray protection; 15mm lead casing

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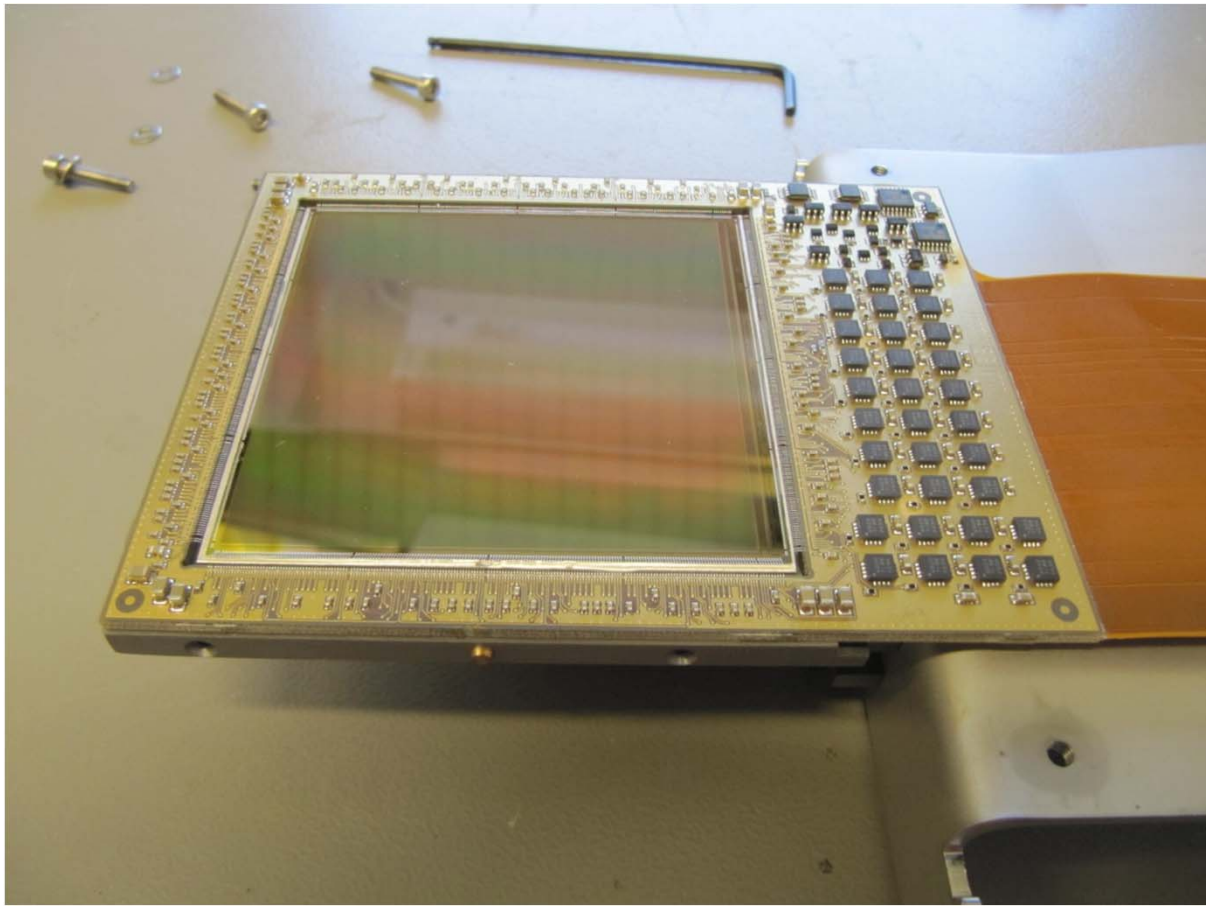
/image sensor with buffers



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/issues around camera electrical design

* No datasheets at project start – a few characterization notes
* Need to clock out a 16Mpixel sensor at high framerate, high resolution
* Sensor needs to be treated as an analogue component;
  * multiple support voltages/currents which could not be known at design time
  * need to dynamically tune voltages
  * could not guarantee that all sensors would operate optimally with the same voltages
* Hyper low noise requirement in analogue domain
* Aversion to compression → Introduction of artifacts

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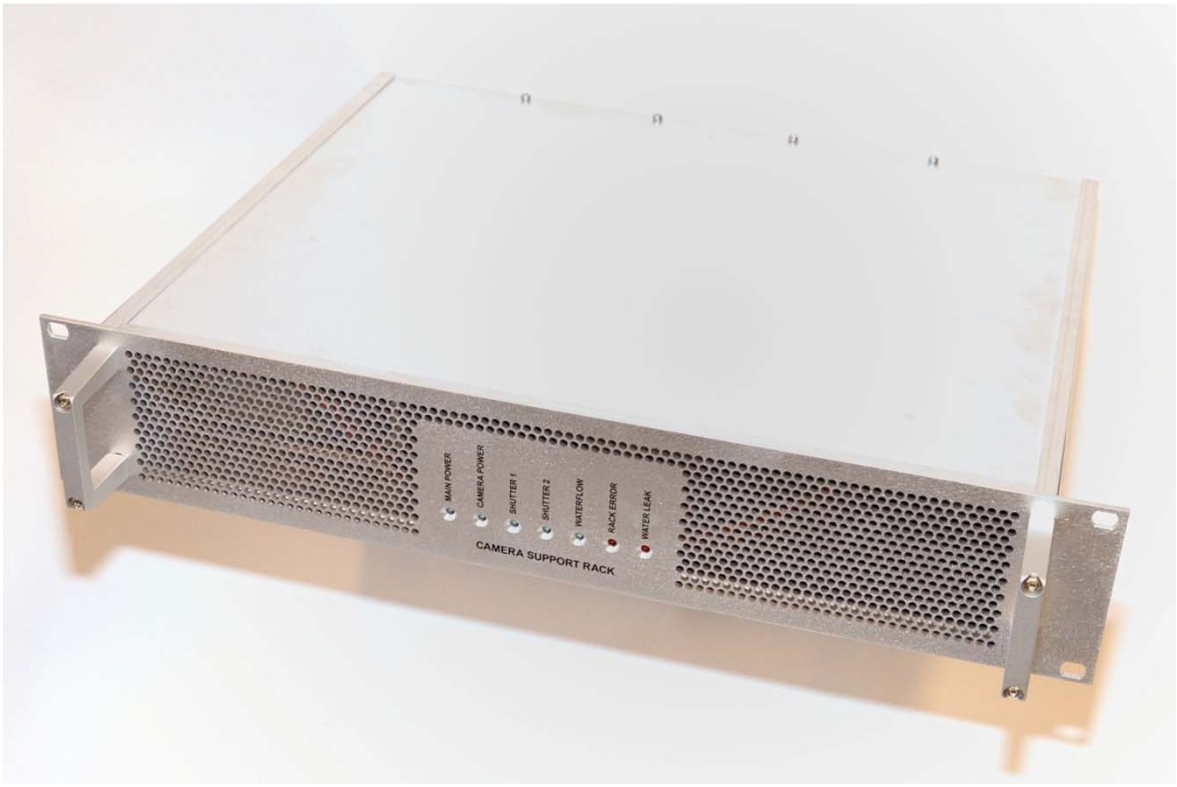
/support rack



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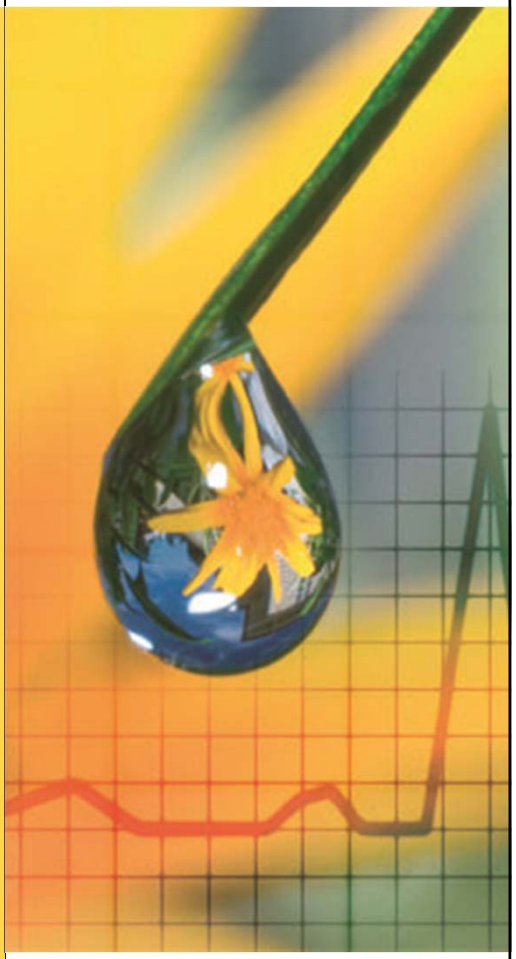
/support rack

* The ‘easy’ bit;
  * No space or power constraints
  * Digital domain → no noise constraints
* Many image processing functions in the rack;
  * Black level setting
  * Image Integration/gain correction
* Comprises 3 boards:
  * PSU (All voltages and support for camera)
  * I/O (10GbE to Camera, GbE to outside world)
  * Processing (3xXilinx CPUs with Microblaze soft cores)
* Designed modularly to reduce critical paths and allow parallel development driven by emergent camera demands



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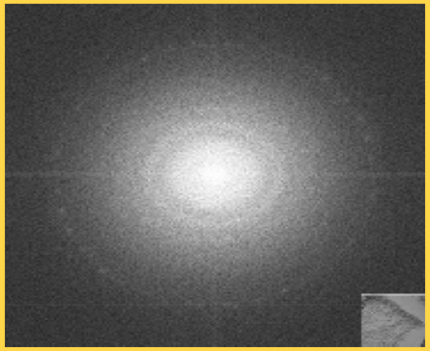
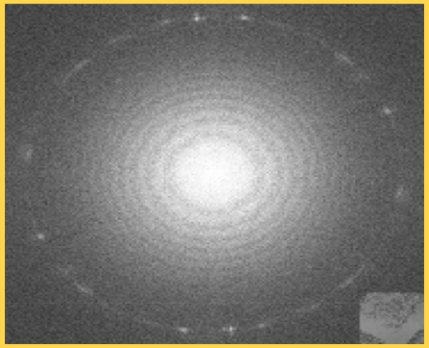
/the result

Conventional 4kx4k sensor



2.3Å Gold lines at 0.9Å/pixel
TEM Mag 120kx*

New 4kx4k sensor



2.3Å Gold lines at 1.1Å/pixel
TEM Mag 96kx*

Source: Presentation by Dr Renato Turchetta at IMAGIC, Kista, Sweden, 24th November 2010

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/key learnings

* Agile techniques allow you to take on technically uncertain projects provided you and your customer both understand and accept the risk associated with such ventures

* You will need to change your target specification according to what you discover along the development path, you will need to exploit the flexibility that agile methodologies give you during development

* It is essential to design for flexibility, even if that's sub-optimal cost wise – otherwise you end up with an optimal, but unfinished, design. Cost optimisation is for release 2.

* You need good people who can understand the consequences of tradeoffs across domains and subsystems

* The payback for stretching the boundries of technical capability are potentially enormous and, in many circumstaces, are well worth the risks assoicated with the venture

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/conclusions and next steps

* agile techniques were always intended to be generally applicable to systems development but have found widespread application in software. To meet the demands of this project we have mapped some of these ideas to systems level development with good results

* without exploiting agile methodologies this project would have taken considerably longer and would have embodied many more design limitations – the end result would not have performed as well

* work continues on further optimisation of the camera system. This new work still uses an agile methodology because many of the original challenges still remain

* agile techniques are not suitable for every project, but we will use them again with confidence on projects that exhibit similar characteristics and uncertainties

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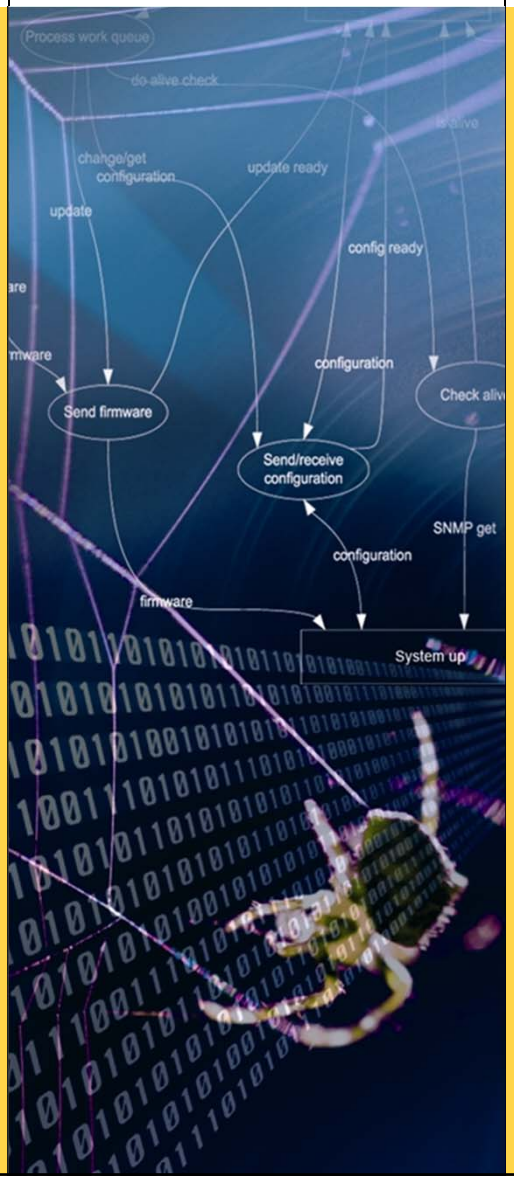

/thanks for listening

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