Reconfigurable Fabric

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Flexible Electronics

- Components built on a thin flexible material
- Provide opportunity to weave computation, storage, and communication into the fabric of the very clothing that we wear
- Biomedical implications
  - computational devices in close proximity to the human body
  - sensors and actuators enable new levels of interaction with the body
    - drug delivery or modulation

Challenges

- Underlying technological differences
  - less mature than silicon-based electronics
  - computation-communication cost tradeoffs
    - organic interconnect has high resistance and capacitance
- Not just a traditional system with flexible form factor!
  - need new architectures
  - need new design tools

Further Challenges

- Different application challenges
  - environmental dynamics
  - physical coupling
  - resource constraints
  - infrastructure support
  - robustness requirements
- Requires radical innovation to realize this vision outside of the laboratory!

Reconfigurable Fabric Vest

- RFabVest
  - Medical vest for sensor-driven personalized trans-dermal drug-delivery
    - medical treatment
    - hazardous environments
  - Low-latency, fine-grained adaption of drug dosage based on continual physiological and possibly environmental measurements
- Sensors
  - interior and exterior
- Actuators
  - drug delivery system

Transdermal Drug Delivery

- Non-invasive
- Diffusion-controlled
- Augmented by electroosmosis
- Already used for
  - cardiac drugs (nitroglycerine, clonidine, etc)
  - hormones (estradiol, progesterone, etc)
- Benefits
  - higher drug concentration
  - elimination of gastrointestinal complications
  - elimination of infections from needles or pumps
  - patient compliance

Fault Tolerant Approach

- RFabVest must have high availability
  - tolerate tears and punctures
    - especially in hazardous environments
  - tolerate device failures
- Redundancy!
  - Replicated functionality
    - sensors and actuators
  - Distributed control
    - no single point of failure
  - Redundant or reroutable interconnect

Additional Benefits of Decentralization

- Sensing and Actuation are distributed across fabric
  - improved detection and remediation
- Control must also be distributed
  - tolerate communication constraints
  - close proximity to sensors and actuators
- Ergonomic considerations
  - electronics should be lightweight and low-profile

High Level Issues

- Reconfigurable Fabric
- E-Buttons
- Reconfiguration in the presence of device malfunction or damage
- E-Button Coordination
- Related Work
- Conclusions

Reconfigurable Fabric

- Large, flexible backplane
- Arbitrarily shaped (i.e. vest or shirt)
- Integrated wiring
  - perhaps with simple switches, latches, etc
  - redundant interconnect
- Complexity of integrated electronics is limited
  - More complex devices can be attached to fabric
  - Well-defined attachment points for external electronics

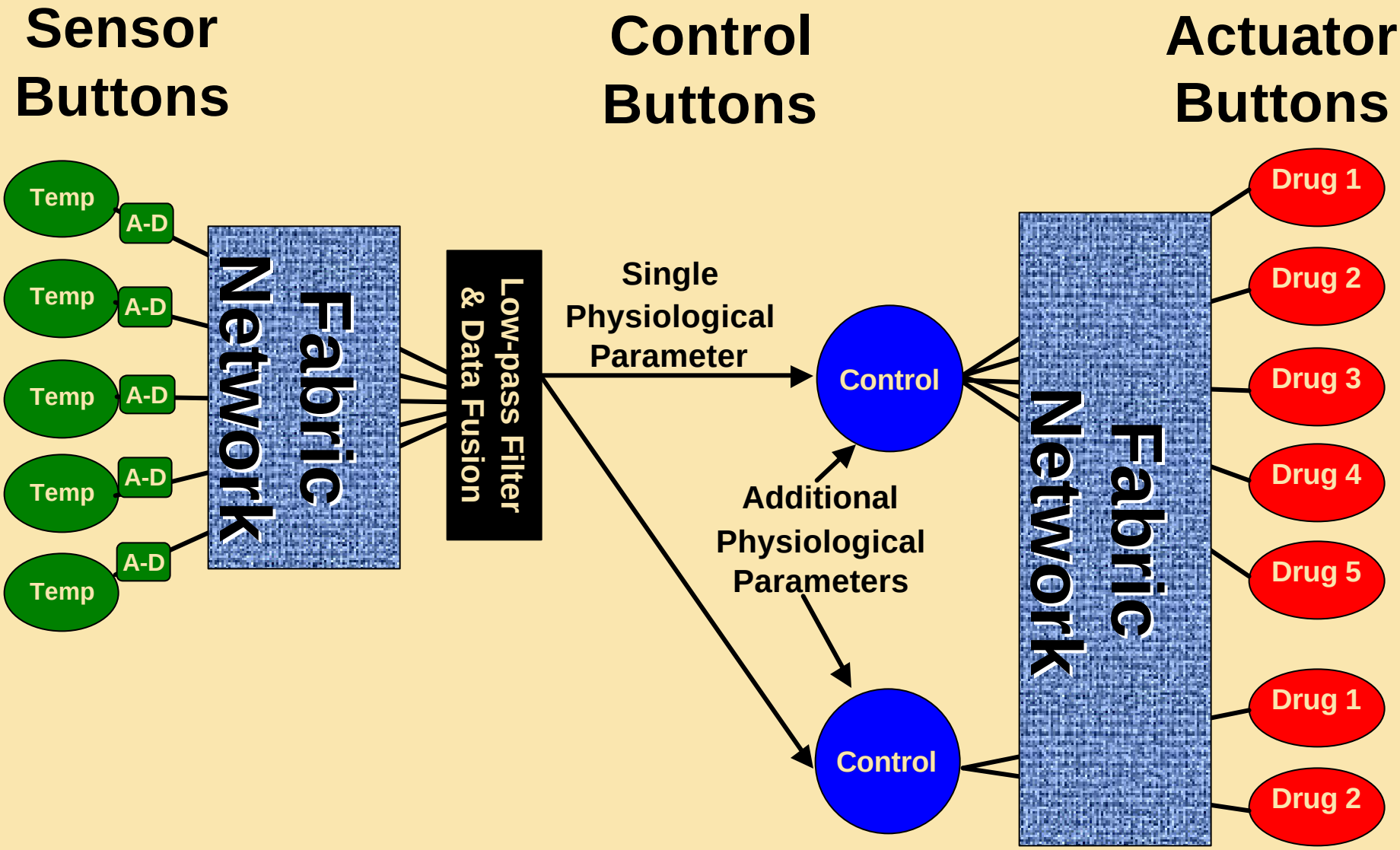
Organic Electronics

- Flexible, rugged, lightweight electronic circuit
  - fabricated at lower temperatures
  - potentially lower cost to manufacture
- UCLA has already demonstrated
  - transistors, diodes, LEDs, memory
- Reconfigurable Fabric
  - Organic electronic devices deposited on flexible polymeric substrates
  - Combination of inkjet printing and self-assembly method

E-Buttons

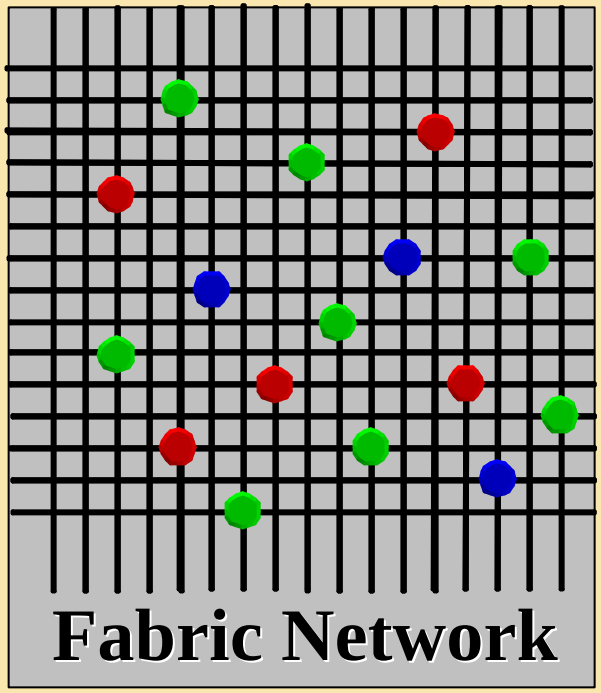
- Software-reconfigurable elements
- Attached to the Reconfigurable Fabric
- Sensor Buttons
- Control Buttons
- Actuator Buttons
- Other buttons?
  - communication, memory, signal processing
- Redundant E-Button placement

Architectural Overview

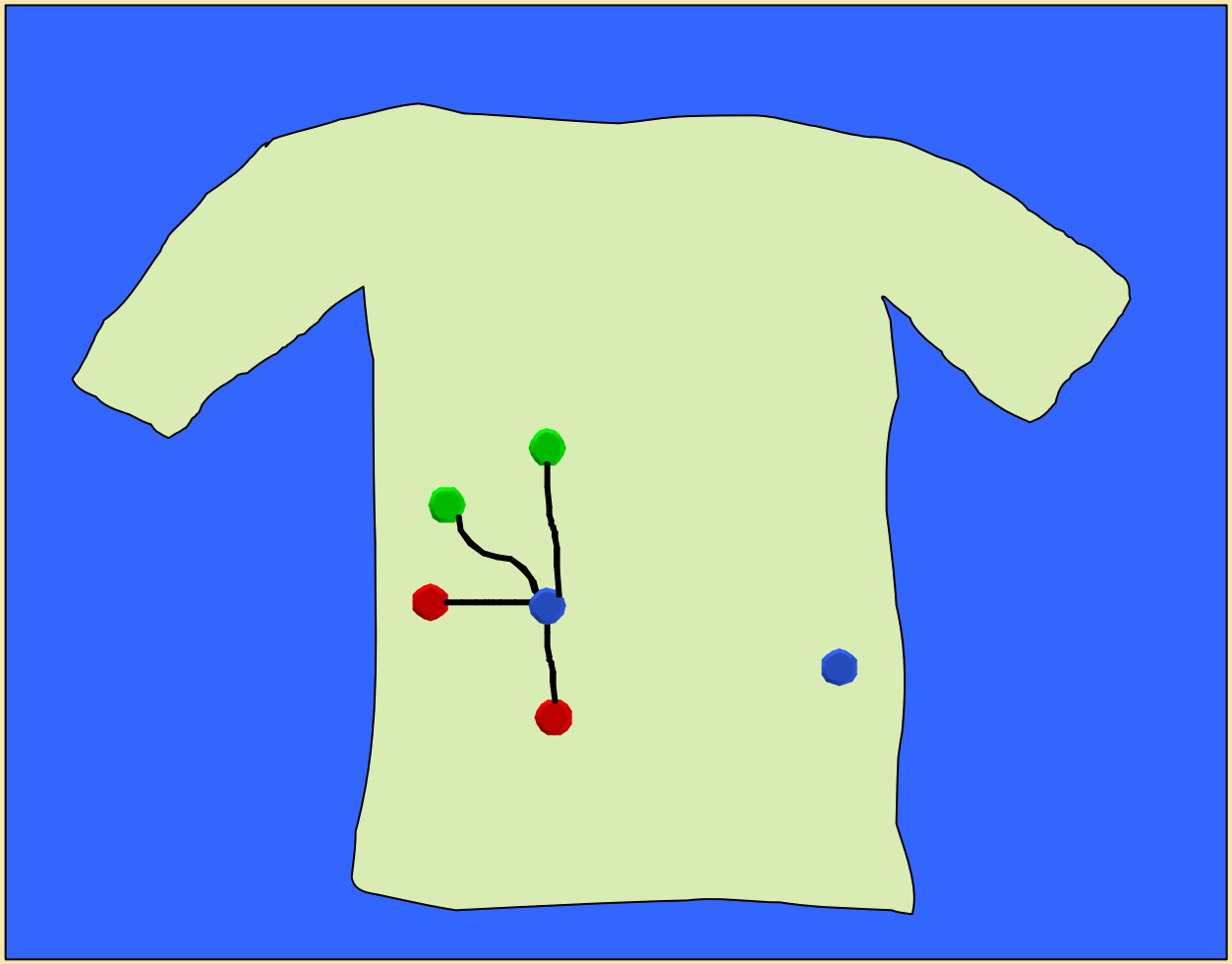


Interconnect Reconfiguration

- RFab must configure itself based on
  - initially available resources
  - ongoing damage monitoring
- 2 alternatives
  - passive wiring
    - connections are redundant
    - multihop packet routers
  - software-controlled, electrical signal routers
    - switches and latches on fabric
    - controlled by distributed reconfiguration management service



Interconnect Reconfiguration



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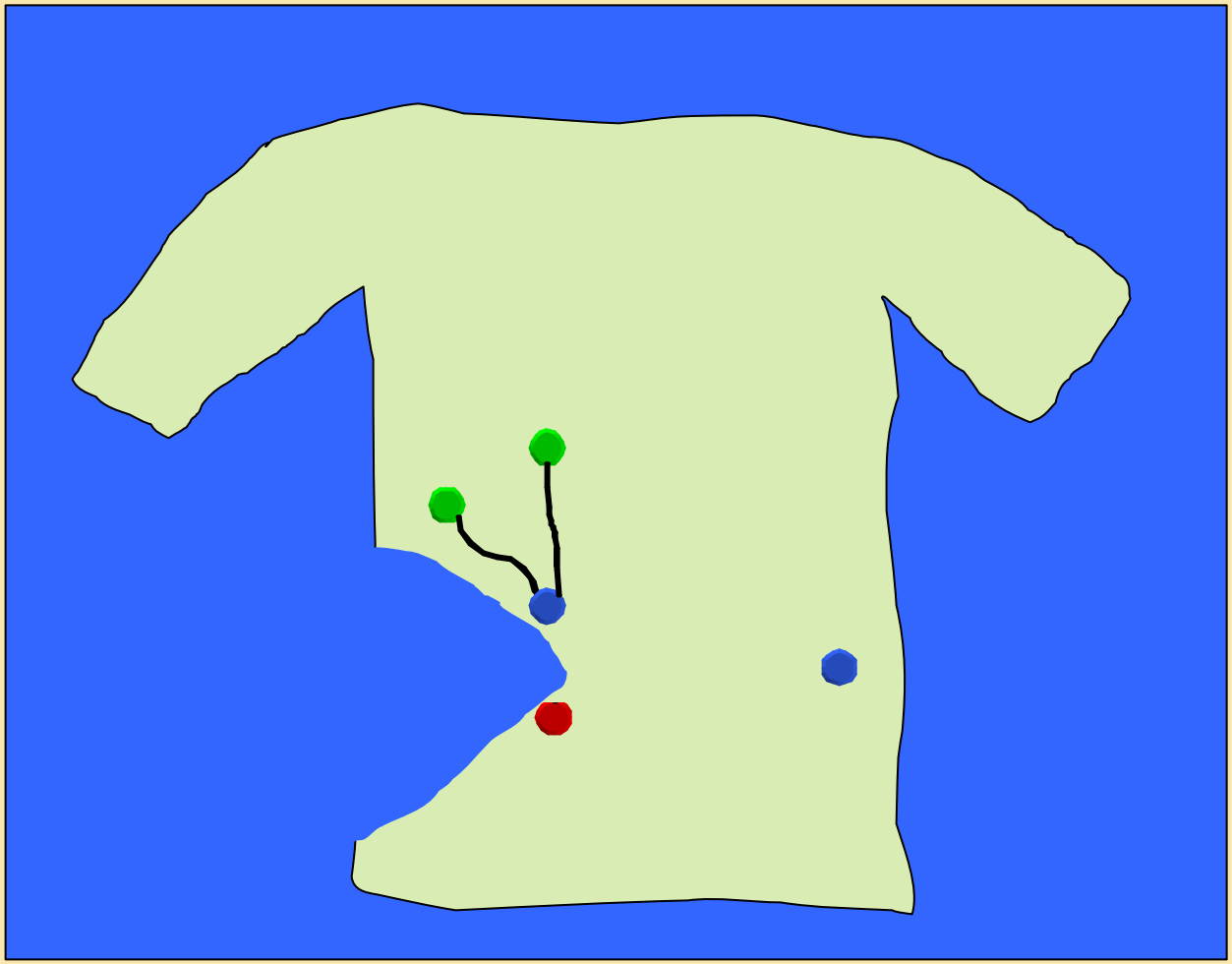

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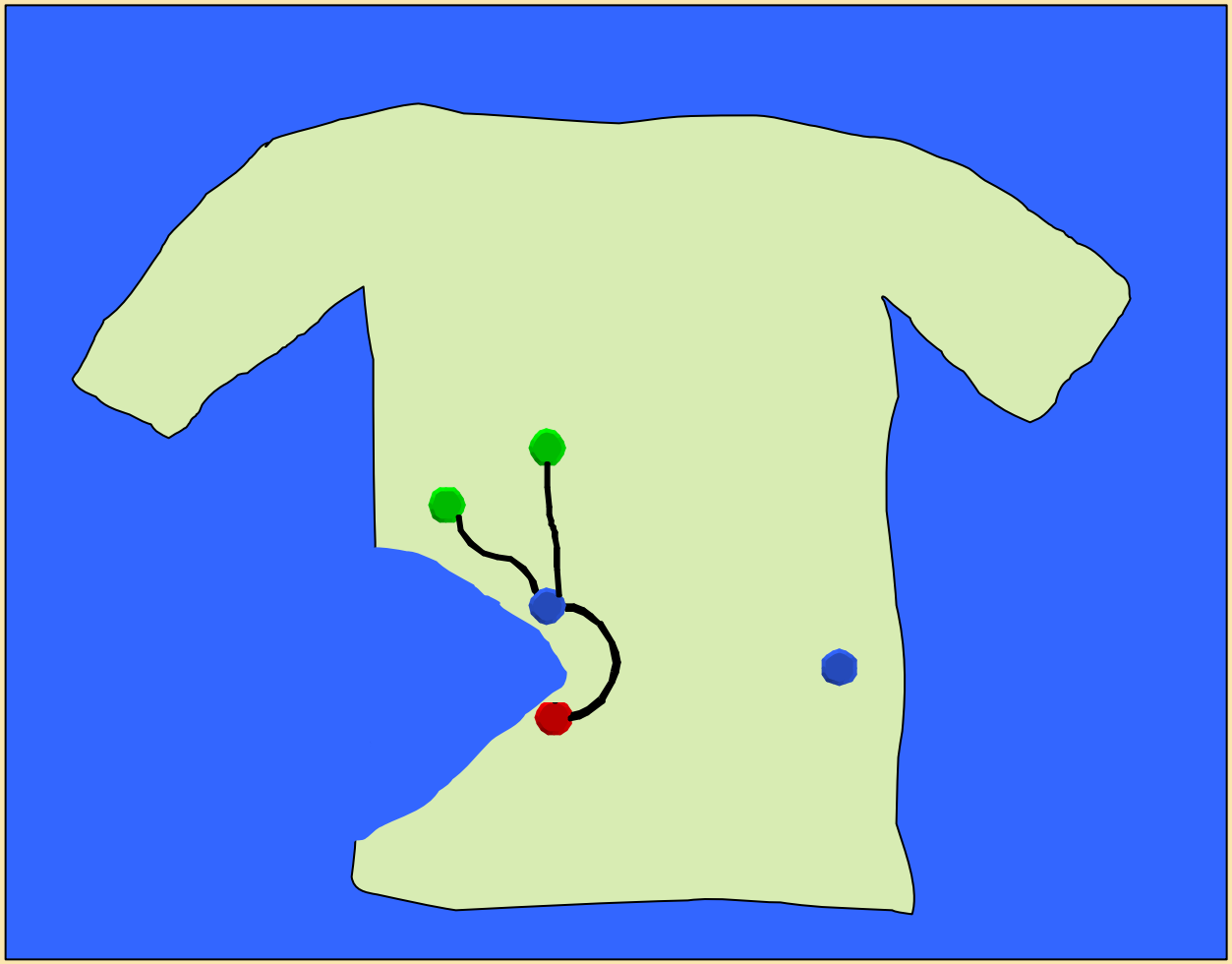

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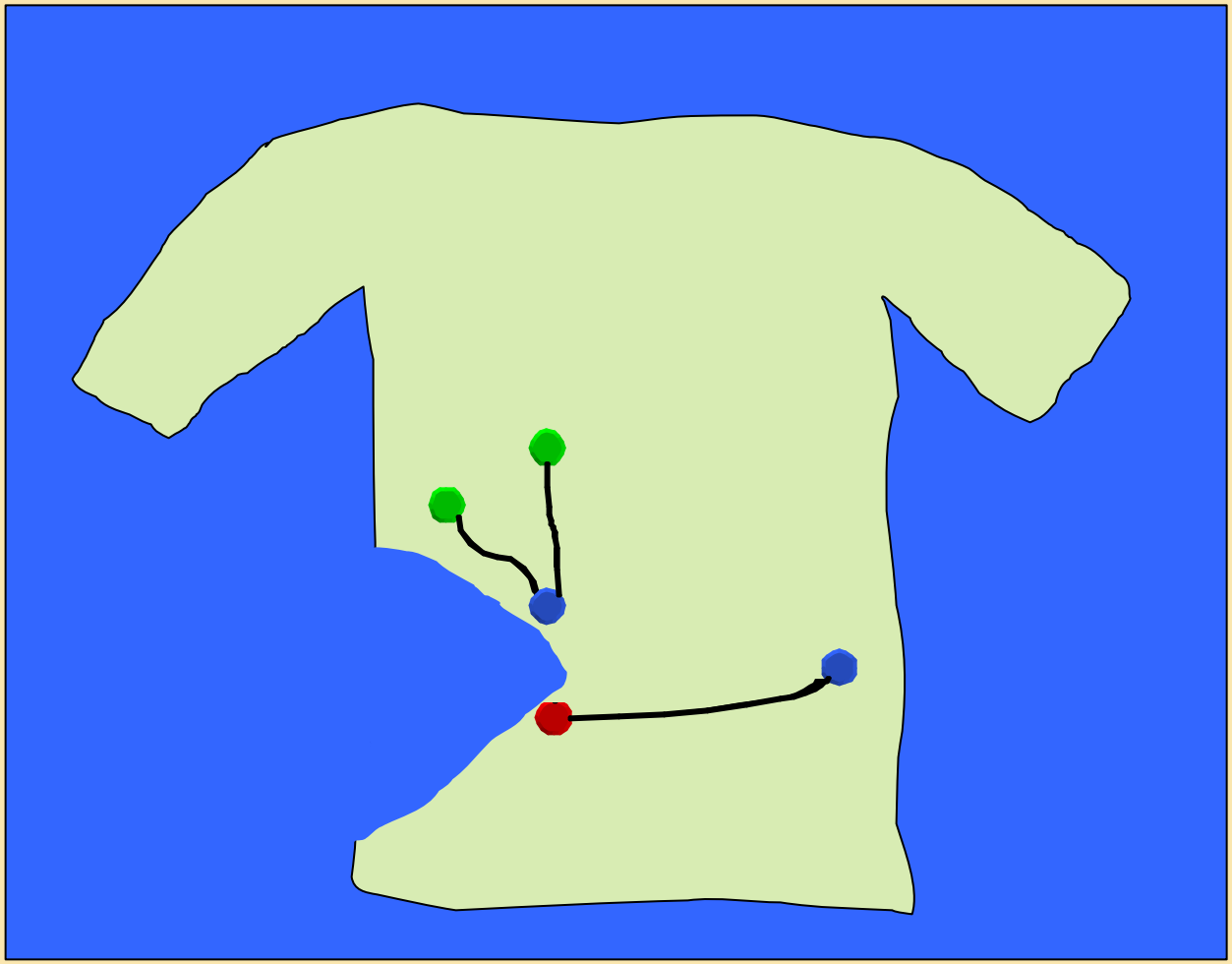

Communication, Collaboration, and Control Primitives

- 2-Way-Diffusion for Control
  - useful in “detection and tracking” systems
  - processing “in the network”
  - initial broad distribution of data
  - then gradients for efficient and effective data communication are reinforced
- Control Groups
  - loosely coupled clusters of sensors and actuators
  - 2-way diffusion will build control groups
  - groups will refresh periodically to allow for discovery of topological changes in RFabVest

Communication, Collaboration, and Control Primitives (2)

- Adaptive Fidelity
  - self-organize to meet current system demand
  - want maximal actuator coverage
  - want predictability and reliability
- Must ensure correct dosage is applied
  - ONLY when required!

Wireless Sensor Networks

- Analogous Features
  - communication constraints are severe
  - systems are tightly coupled to physical world
    - must adapt to unforeseen environmental dynamics
  - self-organizing (i.e. no human intervention)
- Key Differences
  - node deployment is not ad hoc
  - interconnect is not wireless media
  - drug delivery requires reliable and predictable behavior

Power Considerations

- Need to balance
  - Fault tolerance and system response time
  - Energy consumption requirements
- Redundant sensors may be put in sleep mode
  - a given control group can be powered down
  - but communication costs might outweigh benefit
    - communication is costly
- Duty cycle scheme
  - control groups can be periodically woken up
  - shutdown time related to required QoS

Control Button Design

- Range from simple FSMs to more complex embedded processors
  - area, timing, energy, and performance
- Software reconfigurable to meet application needs
  - essential to meet needs of different medical applications
  - minimize energy consumption
  - reduced manufacturing cost
  - Software Parameterized Blocks (SPB)
    - Basic structure is fixed
    - Minimize reconfiguration time

Related work

- The Smart Shirt from Sensatex
  - (http://www.sensatex.com/technology.htm)
  - wearable health monitoring device that integrates a number of sensory devices onto the Wearable Motherboard from Georgia Tech (http://www.gtwm.gatech.edu/).
    - no actuation
    - no dynamic reconfiguration in the presence of rips or tears
    - centralized control
- Other projects:
  - lcs.www.media.mit.edu/projects/wearables/
  - www-2.cs.cmu.edu/afs/cs.cmu.edu/project/vuman/www/home.html
  - wearables.gatech.edu/
  - research.ibm.com/journal/sj/mit/sectione/zimmerman.html
  - www.iis.fhg.de/pwn/technology/body_com/index.html

Conclusions

- Emerging technology of flexible electronics promises to transform biomedical practice and research
- Seamless and fault tolerant integration of
  - communicating computation and storage resources
  - physiological and environmental sensors
  - biomedical actuators
  - all in close proximity to the human body
- RFab Vest is a driver application for new technologies and architectures in the field of flexible electronics

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