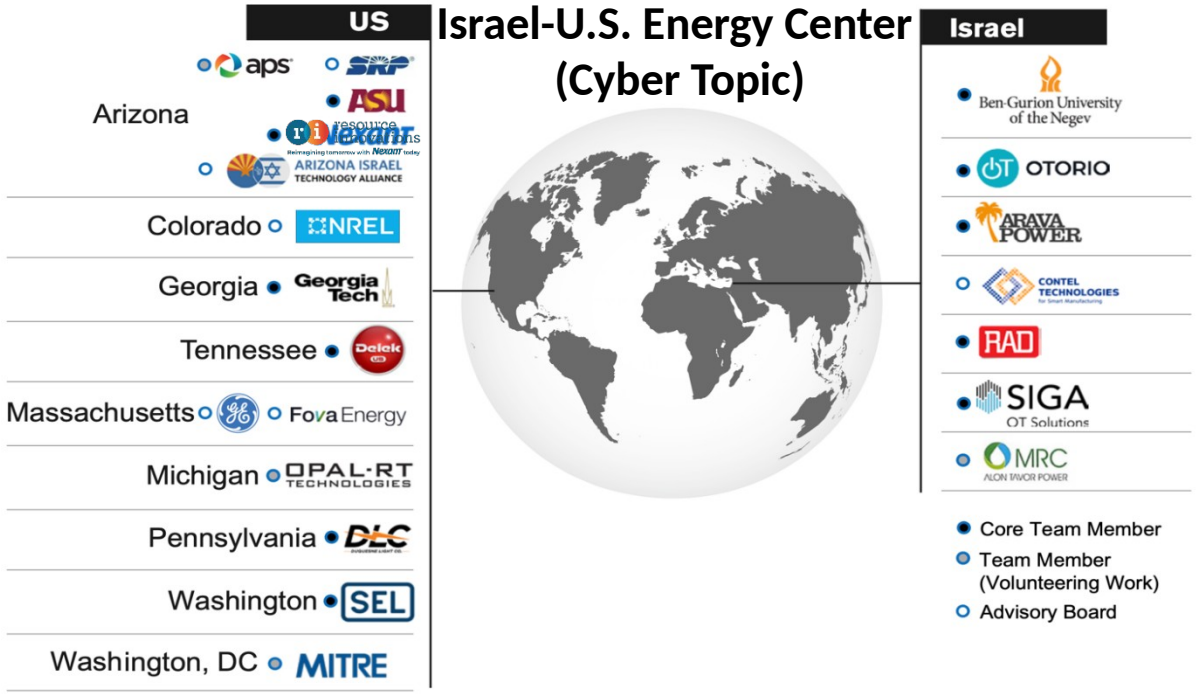
Comprehensive Cybersecurity Technology for Critical Power Infrastructure AI-Based Centralized Defense and Edge Resilience



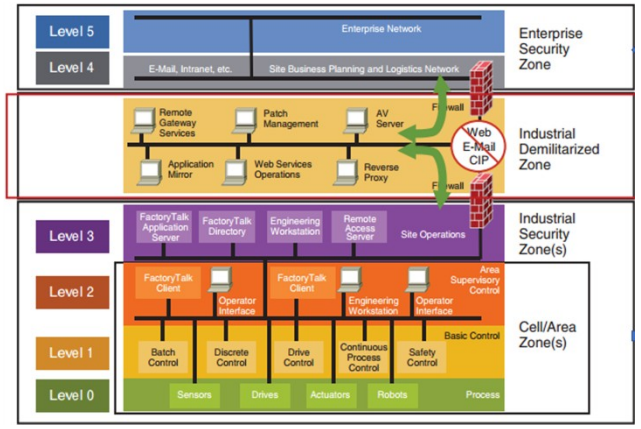
Prepared for

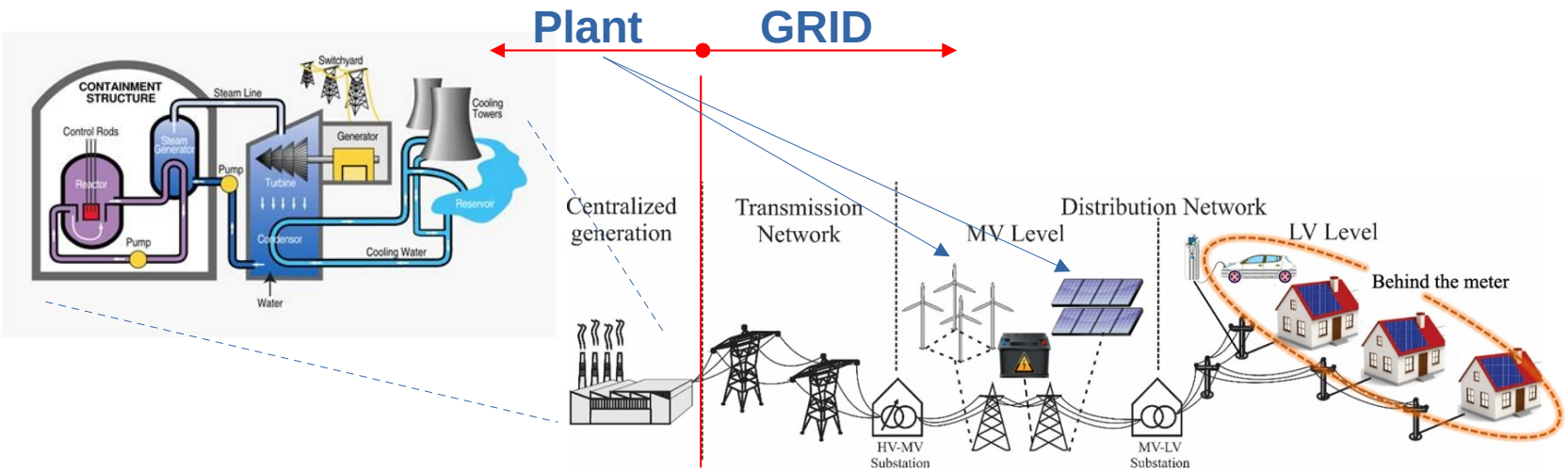
Eitan Yudilevich, Eynan Lichterman, and **Tal Fischelovitch**

BIRD

Aug. 25, 2022

CPS Devices in Energy Infrastructure





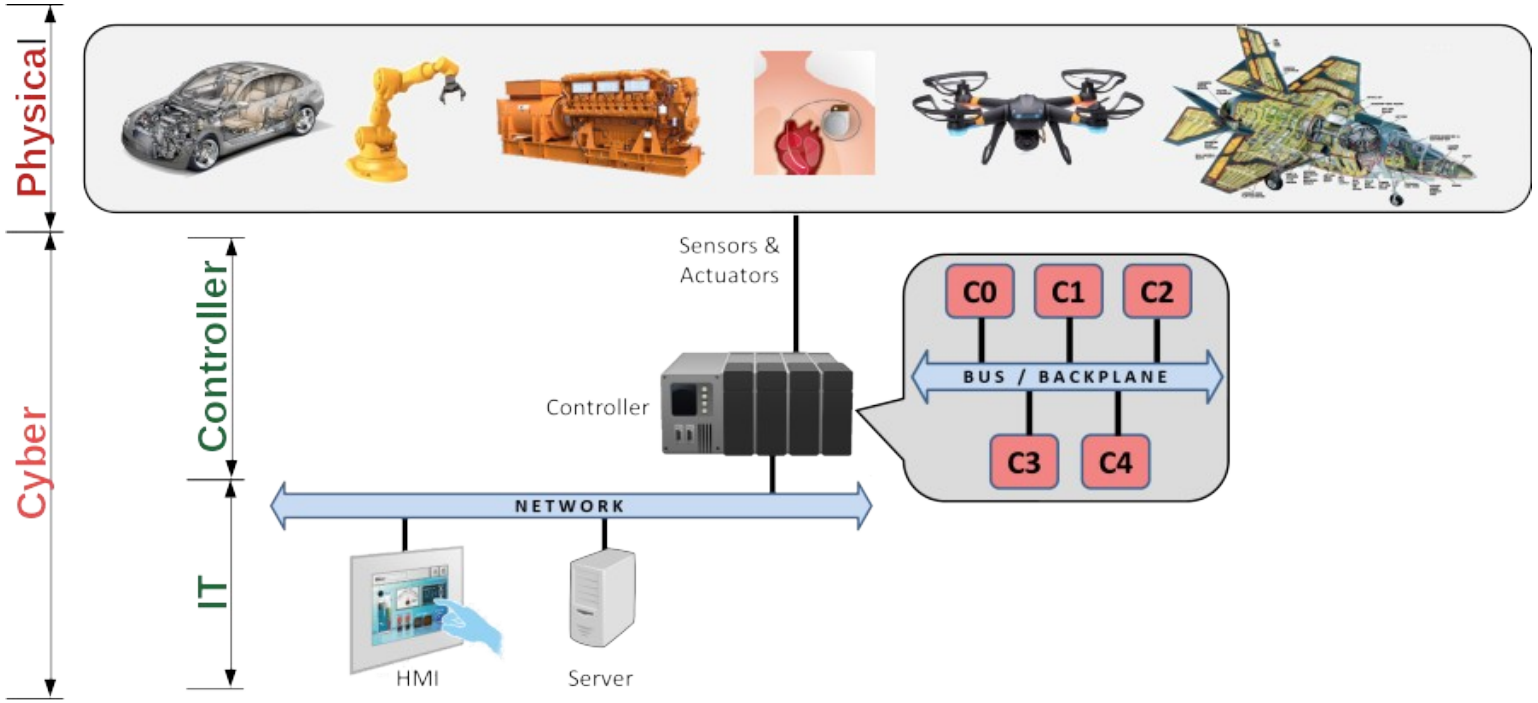
Power Transmission & Distribution GRID

- Small number of component/device type, large number or replication; rather homogeneous
- Underlying process: events propagation

Power Generation Plants

- Large & diverse component/device types, low number of replication; heterogeneous
- Underlying process: varies

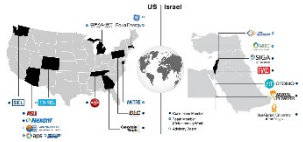
Device Level Security: Robustness from the Ground Up



- Effect of Compromised Device:
  - Compromised Devices → '**Insider Threats**'
  - **Lie** to monitors – doing one thing, reporting another (e.g. Stuxnet)
  - Transport-Layer/communication **encryption** generally **irrelevant** (data is generally ephemeral) – protecting the attacker. Although, **authentication** is **relevant**.

- Cyber Attack Resilience
  - Relying on CPS (controller) properties to tolerate direct cyber attack
  - Agnostic to the specificity of the attack (malware)
  - Complementary multi-factor authentication for firmware update, help to complete the security posture.

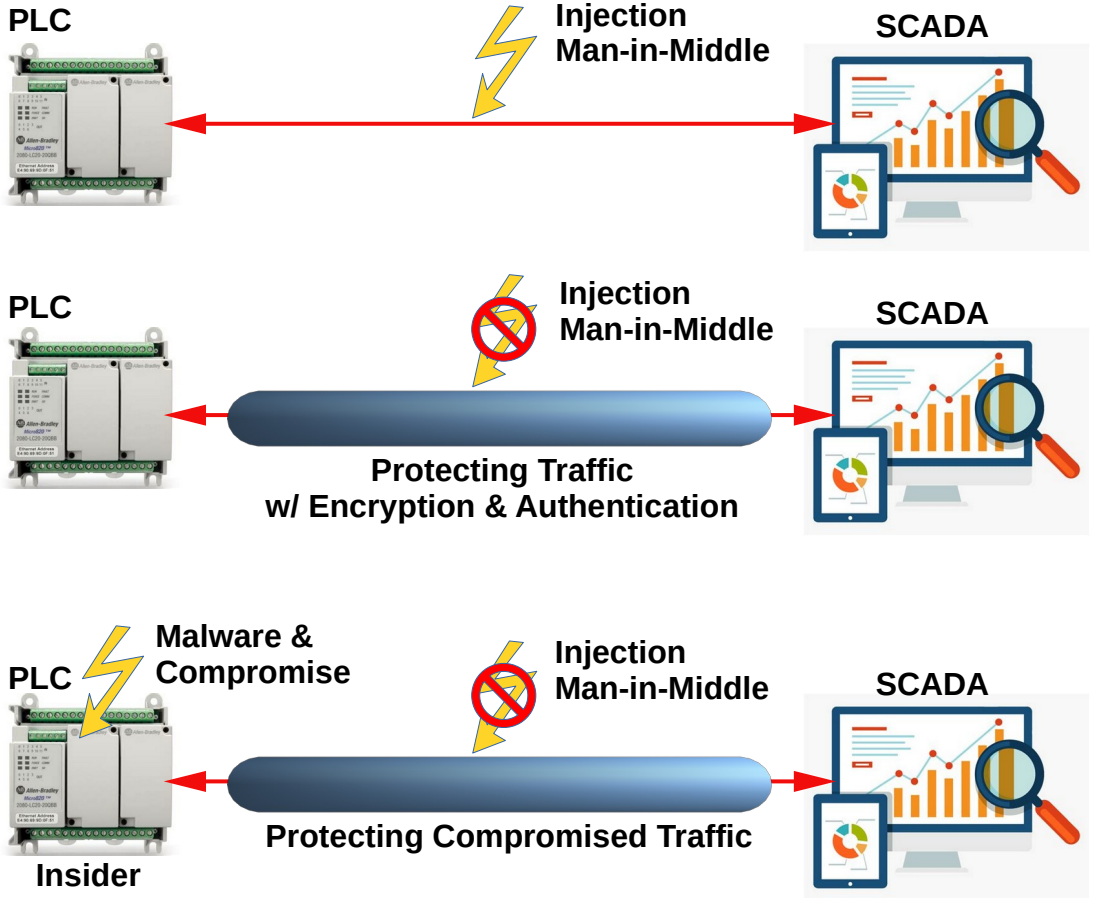
Device Level Security is Paramount



- **Compromised Devices act as Insider threat**
- **Communication & Network security:**
  - Authentication is always beneficial.
  - Encryption reduces attacker's ease of tracking & spoofing,

    but also complicates defender's monitoring efforts.
  - Effective against data injection & Man-in-the-Middle.
  - **Not** effective against **Insider Threats.**

Robust & Timely Defense and Resilience Cyber Physical Systems' Device is Highly Desired



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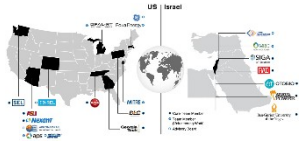
CPS stability concerns



Cyber **Physical** **Systems**

Supporting
Is a "means to an end"

Primary Concern
"Stability & Integrity"

Cyber-attack resilient solutions should be primarily defined and motivated by physical requirements

The goal is for the physical subsystem to be stable, and not necessarily the cyber subsystems

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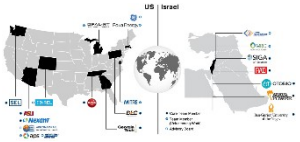
CPS controller properties



Periodicity

- Continuous observe and control loop (scan cycle, usually ~1-300 Hz)

Periodicity tolerates some loss of inputs or data

- Sensitive to latency variations
- Not performing open-ended, general-purpose tasks like IT

Inertia

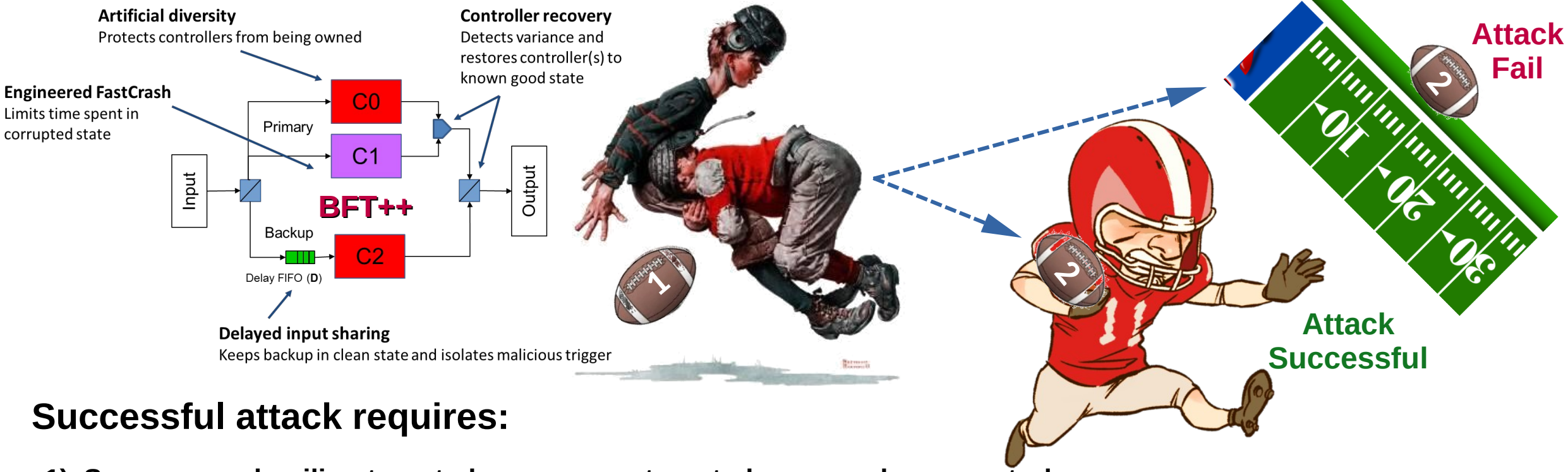
- Physical systems have inertia
- Effect: can tolerate some bad cycles and still maintain stability
- Missed output
- Wrong output (sensor blip, etc.)
- In context of cyber attack:

Inertia provides some natural (output) fault tolerance

- Not immediately uncorrectable
- How long is system-dependent

Periodicity and Inertia enable BFT++

Cyber Attack Invariant



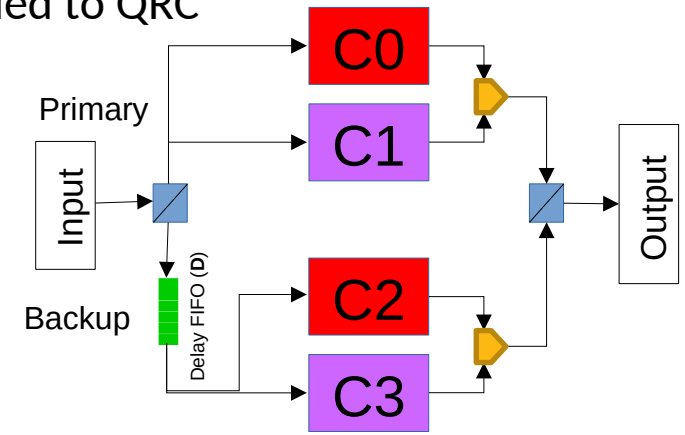
Successful attack requires:

1) **Success on derailing targeted program --> targeted program loses control**
   - Defense: avoid any bugs and flaws (formal methods, protection techniques)
2) **Success on capturing control --> attacker controls program execution**
   - Defense: avoid any predictability, cross-check with diversified version

ONR's RHIMES (BFT++)

BFT++ v1 (Vanilla) – NRL

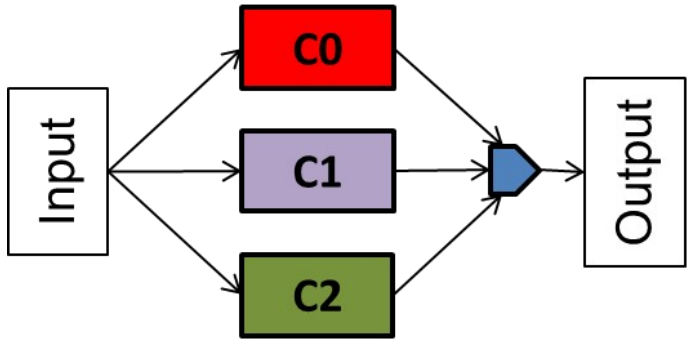
Original BFT++ applied to QRC (QRC++)



BFT++ v2 – Georgia Tech

More **robust**, more **costly,** protection is diversified

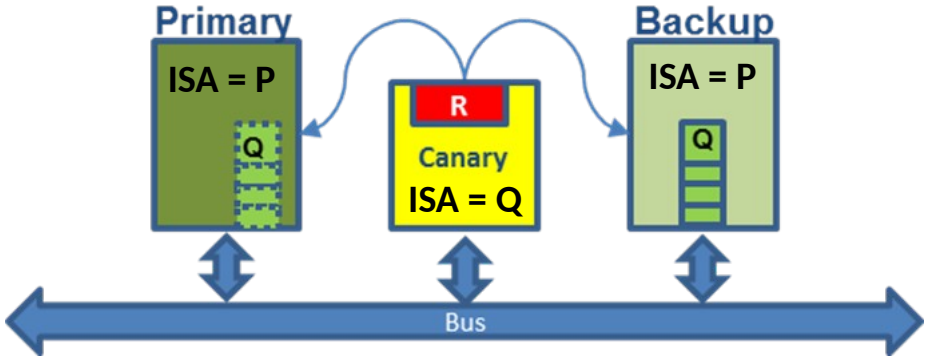
Diversified protection sets provides comprehensive protection with reasonable distributed overhead



BFT++ v4 (Rum Raisin)

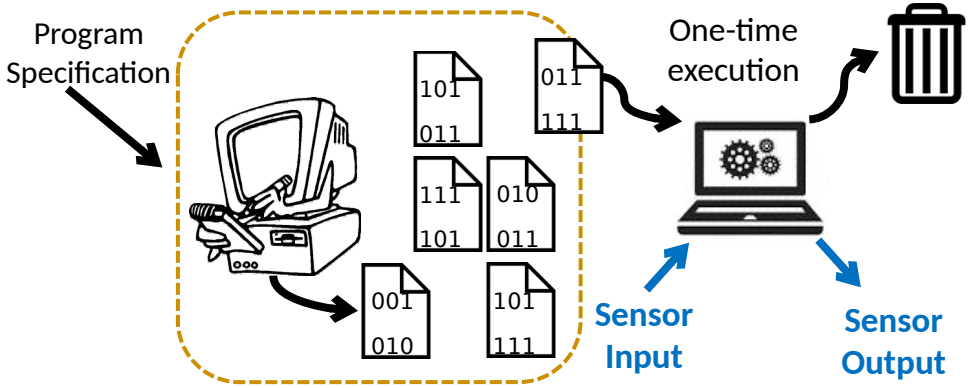
Variation of the original: ISA diversity

Q = delay queue
R = recovery trigger logic



BFT++ v3 – Columbia University

Lightweight, **probabilistic** guarantee, needs **no redundancy**



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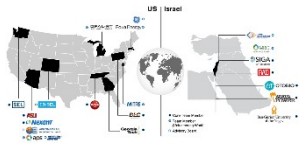
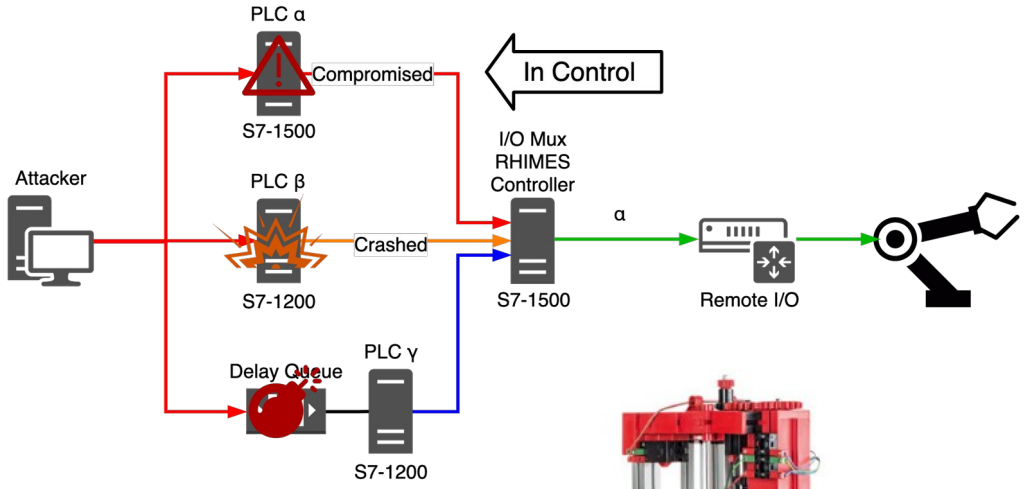
MITRE's RHIMES Laboratory Experiment

contributed by: Matt Mickelson, MITRE



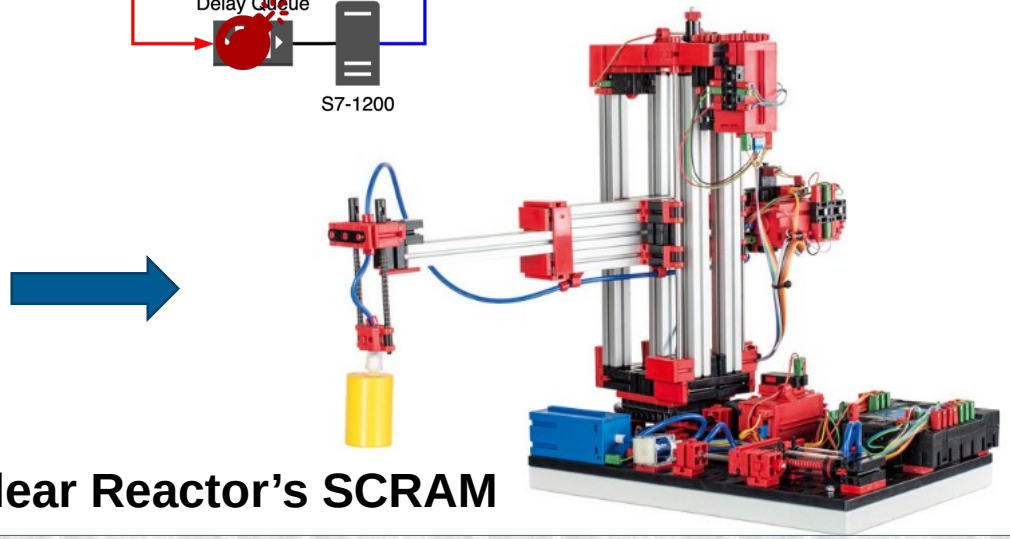
Hypothesis: The time it takes to detect a crash and switch to a hot backup PLC is less than the time it takes to lose a "puck" due to inertia of the gripper losing grip.



Hypothesis Confirmed

Full recovery is acquired if the first 2 PLCs can be rebooted and reassume control.

MITRE



Emulating Nuclear Reactor's SCRAM

Demonstrated continuous operation despite repeated cyber exploit

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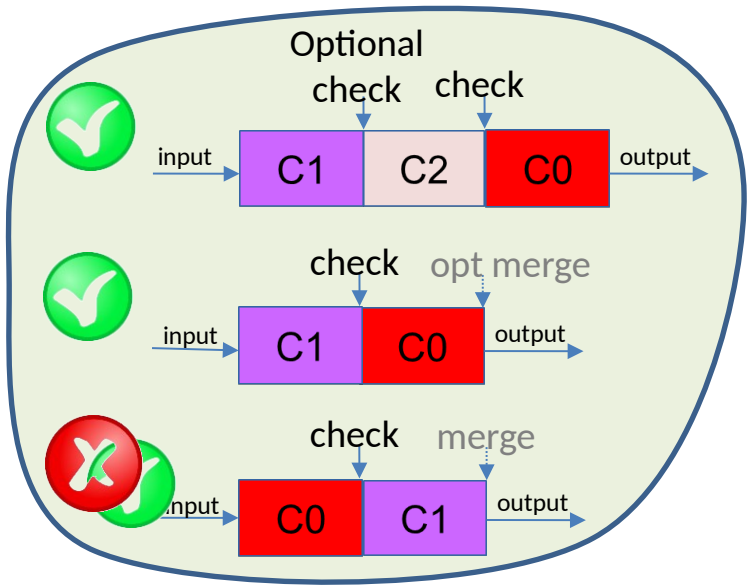
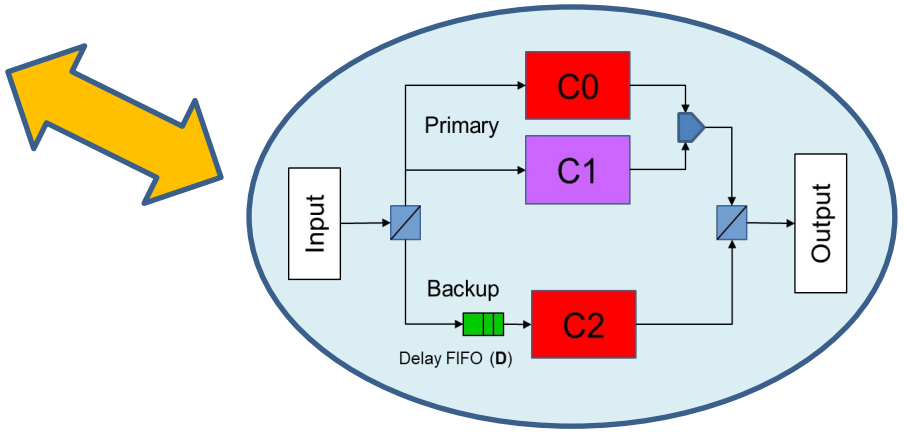
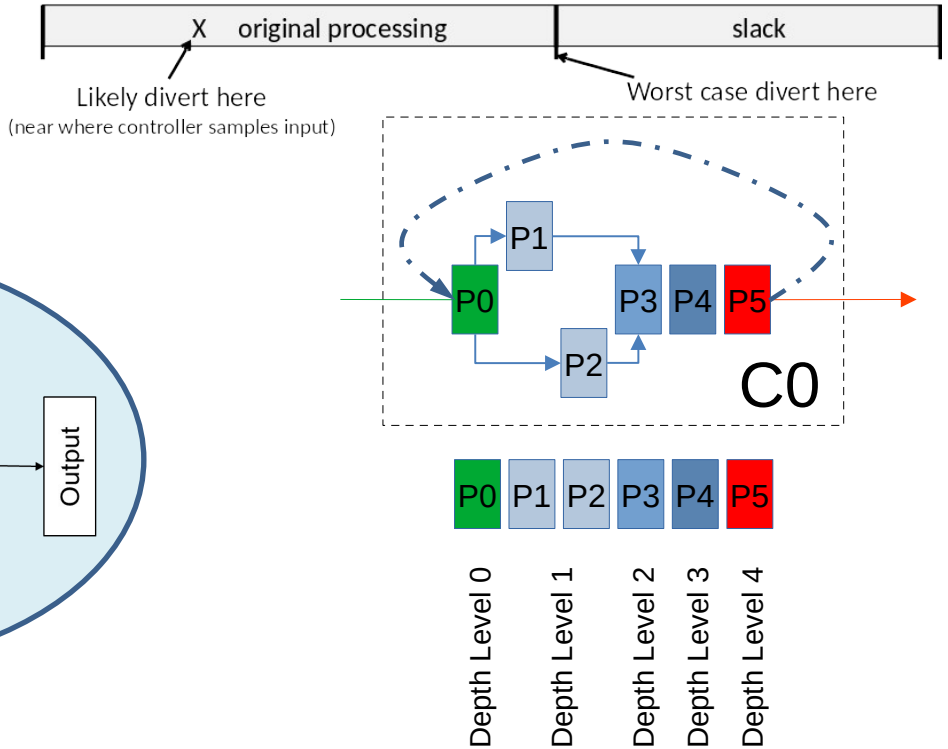
Diversified Redundancy on Single Processor
Parallel vs. Serial



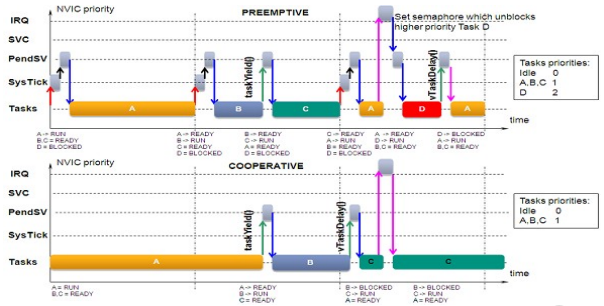
Legends:
- **C0** Original control program
- **C1** & **C2** Diversified programs
- If **check** fails, drop input



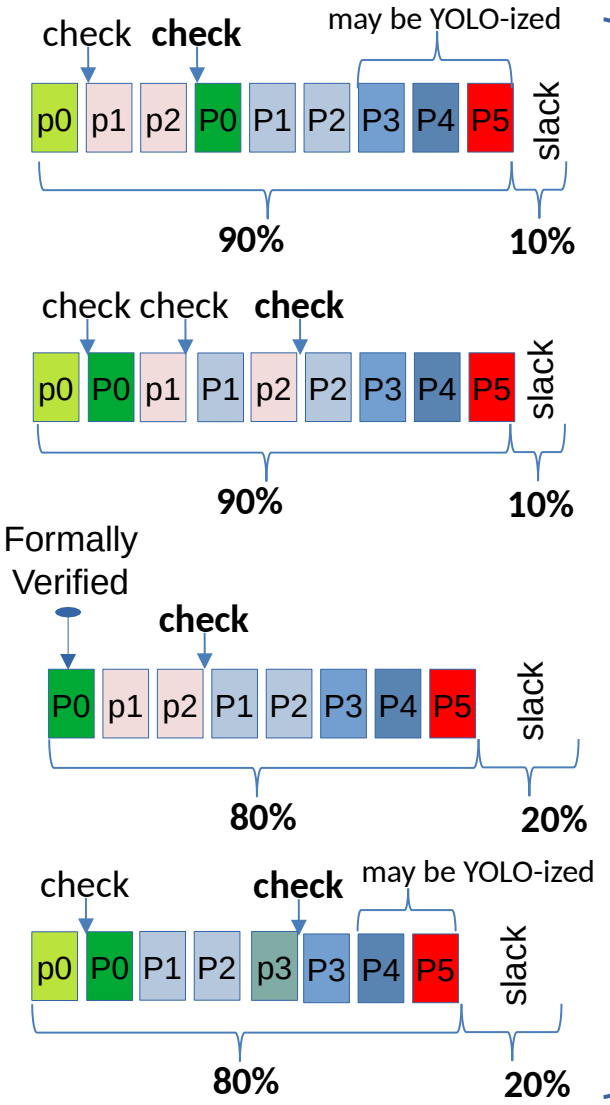


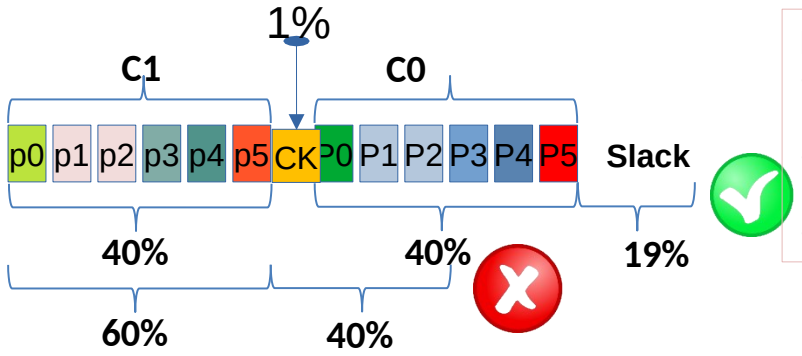
Design parameters:

- Slack availability
- Number of sensitive processes
  - Depth relative to input
- Pre-emptive vs. Co-operative scheduling



Diversified Redundancy on Single Processor
Serial in Finer Granularity

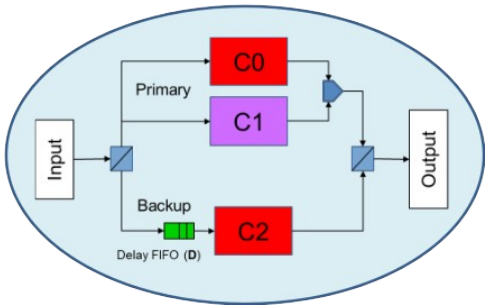




Legends:
- **C0** Original program
- **C1** Diversified program
- If **check** fails, drop input

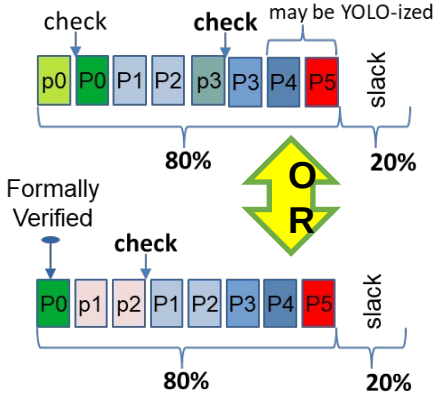
1001 ways to implement BFT++ concept w/ sub-process replication;
- **Diversified replication can co-exist w/ Formal-Methods, Protections & YOLO**
- **Engineering for sub-processes replication depends on:**
  - **Available Slack & Desired Slack,**
  - **Sub-processes' Depth Level,**
  - **& particular sub-process' properties**

Cyber-Attack Resilience for CPS – Part B



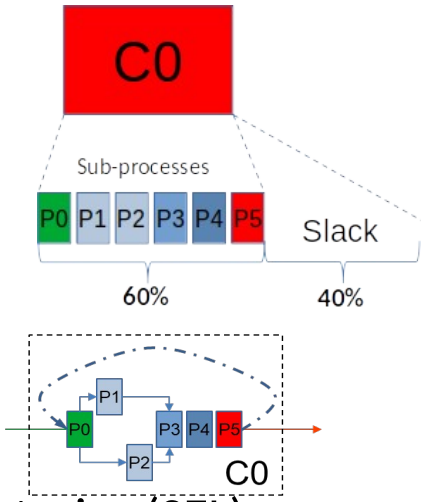
BFT++

equival ent



SubProcess BFT++

SubProcess BFT++ Engineering **Tool**

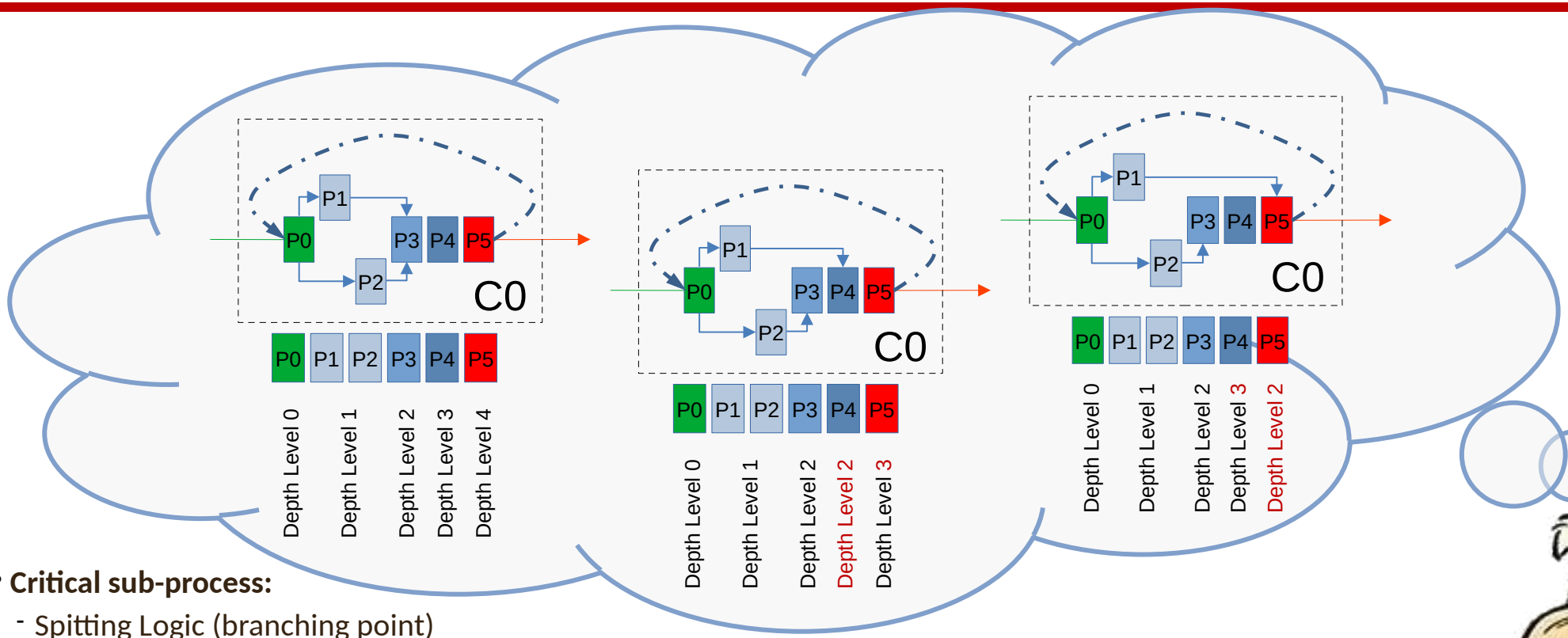


We plan to integrate the SubProcess BTF++ engineering tool into ~~Schweitzer Engineering Laboratories (SEL)~~ open source PLC design tools and environment.

Impact:

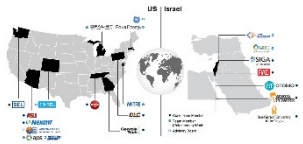
- Alleviate the need for redundant device in BFT++, providing cyber attack resilience for application which cannot afford device redundancy
- Significantly widen the applicability of BFT++ and resilience against direct cyber-attack
- BFT++ automatically isolate offending data, can be communicated to other system components, e.g. SCATOPSY, RAM$^{2.}$, to prevent repeat attack.
- Integration into ~~SEL~~ open source PLC (or Siemens) design environment for ease of deployment and dissemination.

Theory & Formulation to Develop



- **Critical sub-process:**
  - Spitting Logic (branching point)
  - Gating Logic (where 2 or more flow merge)
  - Sensitivity Level (minimum distance to inputs)
- **Need to develop Theory & Formulations**
  - Identification of key sub-process (Sensitivity Level, Gating & Splitting Logic)
  - Sub-Process BFT++ per-component mode selection/trade-offs: redundant-diversified, YOLO, or Formal methods

Cyber-Attack Resilience for CPS – Progress



Current status:

- Coordination meetings with SEL:
  - Initial Coordination meeting on April 5th 2022
  - Training for SEL RTAC development tools and environment on April 18th 2022
  - Meeting for further deep dive into SEL's:
    - Operating System implementation
    - Compiler and code generation process
    - Real time scheduler
    - Etc.

  SEL cannot support transition
- Changing Transition Plan:
  - Transition into open source OpenPLC
  - Siemens ???

- Started on May 1st 2022
- Initial research will use an open source PLC environment: **ClassicLadder**.
  - For experimentation platform and
  - For analyzing generated codes for PLCs
    - Understanding scheduling structure
    - Studying design trade offs for integrating sub-process BFT++
  - A Linux toolset, as oppose to Windoze
- Exploring OpenPLC for R&D (instead of ClassicLadder) and Transition
- Future: integration into OpenPLC ??? design tools and environment

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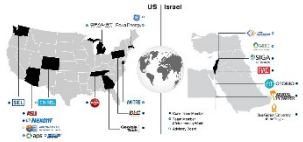
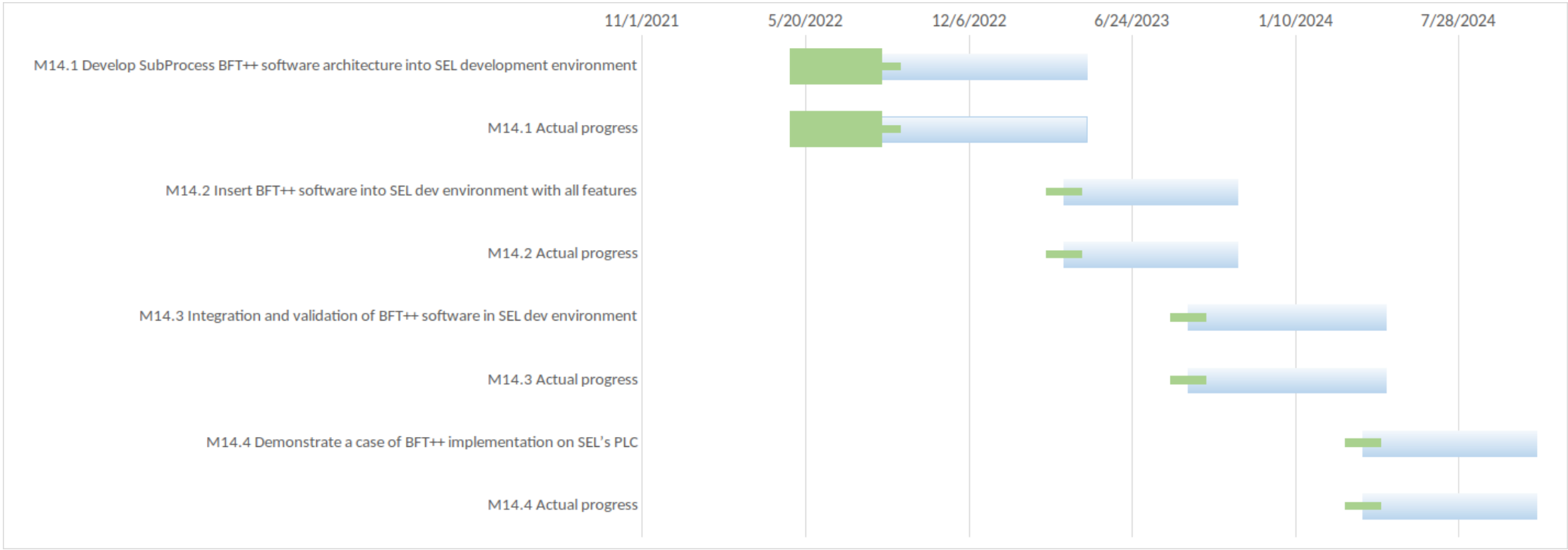
Schedule & Milestones:





- We are starting in May 2022
- Team:
  - Dr. Sukarno Mertoguno
  - Interviewing a new PostDoc 8/31
  - M. Faraz Karim, Ph.D. student visa isn't completed in Pakistan, delayed arrival

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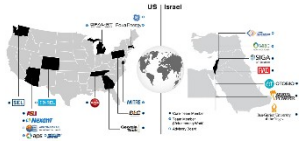

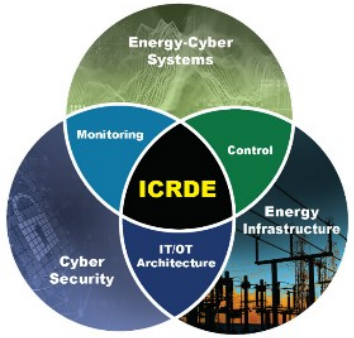

Theme 1: Cyber-Physical System (CPS) Data Preparation

- **Project 1**: Physical Processes as Cybersecurity Assets
  - **T1: Realization of advanced energy management applications**
  - **T2**: Digital representation of physical processes and operational process modelling
    - **T3**: Data collection and aggregation
- **Project 2**: Knowledge Base Establishment and Representation Learning of Threats
  - **T4**: Multi-level threat intelligence knowledge base (MITRE)
    - **T5**: Adversarial mimicking (Theoretic)
    - **T6**: Threat hunting (Actively learning)

Theme 2: Data Analytics for Monitoring

- **Project 3**: Cyber Attacks Detection of IT/OT Architecture
  - **T7**: Malware threats mitigation (Smart enemy? Reduce probing and plan)
  - **T8**: Detect event mimicking attacks
    - **T10**: Multilayer anomaly detection (Uncertainty)
    - **T9**: False Data Injection (Physical Embedding)
  - **T11**: AI-based intrusion detection (Engage operator)
  - **T12**: Explainable cyber-AI analytics (Metric + Temporal)

Theme 3: Control and Validation

- **Project 4**: Cyber Resilience and Robustness for Control Actions
  - **T13**: Firmware verification (Edge)
  - **T14**: Attack tolerance (Insensitive to the attack)
  - **T15**: Self healing and auto-remediation (Optimization)
    - **T16**: RL control for CPS (Advise Sys Operator)
- **Project 5**: Future-Proof Architectures
  - **T17**: ICS security by design
  - **T18**: Hardware in the loop