Aalen University

Supporting Augmented Reality Industry 4.0 Processes with Context-aware Processing and Situational Knowledge

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- Worked for 14 years in the software industry in the Silicon Valley and in Germany doing research and development.
- Since 2004 he has been a Professor of Computer Science at Aalen University in Germany, teaching in the areas of software engineering.
- His research interest is to leverage technologies and techniques to innovate, automate, support, and improve the production and quality of software for society.

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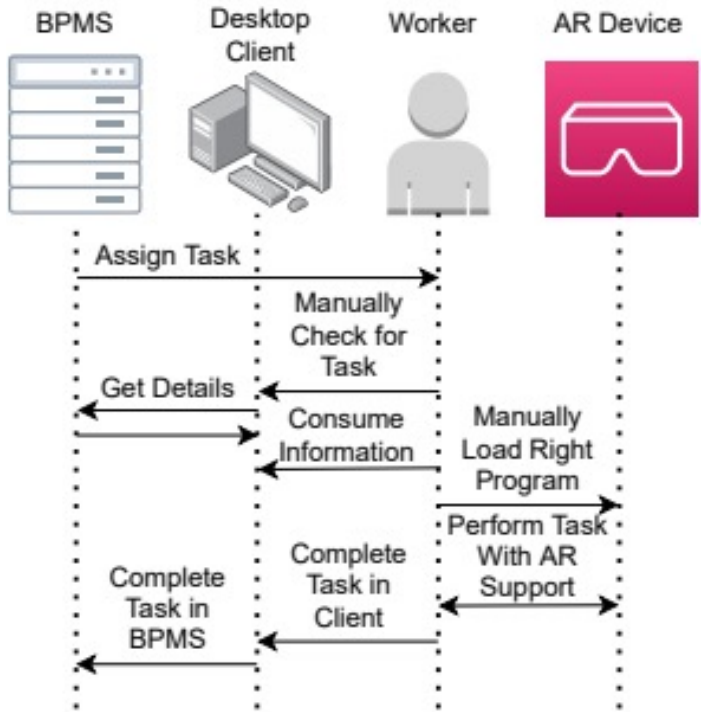
Industry 4.0 and Smart Factory Challenge: Automation & Humans

- High degree of automation and digitalization
  - Yet certain complicated tasks - such as machine maintenance - must still be executed by human workers
- Such human-based tasks can be supported by Augmented Reality (AR) devices
  - Currently AR task support is highly manual from a process perspective
- To better integrate AR tasks into Industry 4.0 processes:
  - They should consider various contextual factors such as:
    - Live sensor data from machines
    - Environmental worker safety conditions or regulations
  - These are not yet well integrated into the *global production process*
- Problems:
  - Manual task assignment or suboptimal automated task assignment
  - Over-exposure of workers to hazards like noise or heat
  - Unawareness of worker break, overtime, qualification, regulations, or labor cost
  - Delays in the production process

Technical Problem: Context-Awareness

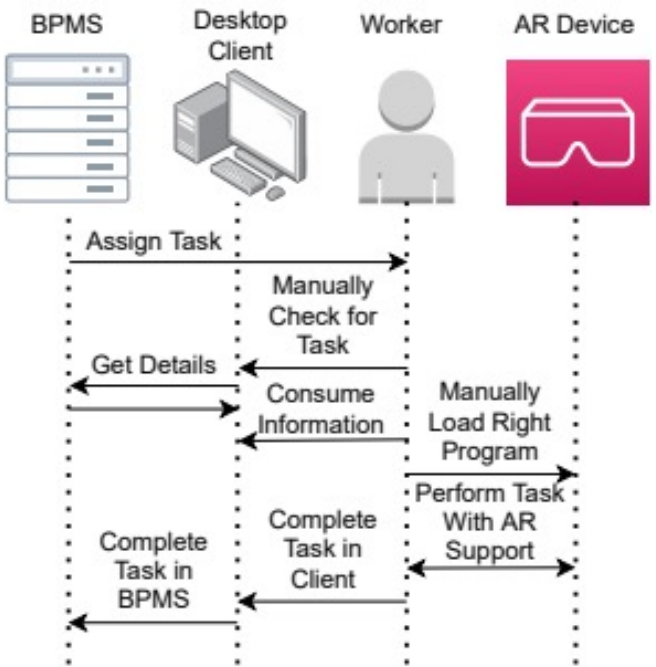
- Business Process Management System (BPMS)
  - “Knows” and accesses only its own process state and process context
  - Unaware of “other” things going on
  - Typically relies on its own web- or rich-client interface for human interaction
- Augmented Reality (AR)
  - Requires separate hard- and software platforms
  - AR devices are typically controlled manually
  - Lacks inherent automated workflow support and integration with BPMS



Address the gap between AR and BPMS context-awareness

Solution: Augmented Reality Process Framework (ARPF)

Before



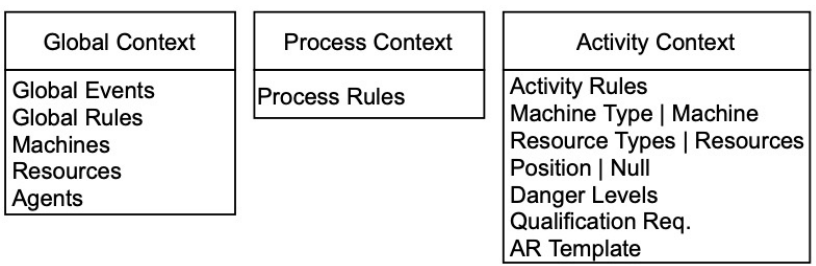
After

- Combines context-aware processing, situational knowledge, and AR support in one solution
- Improved task assignment thanks to context-awareness and situational knowledge

ARPF Context and Actor Models

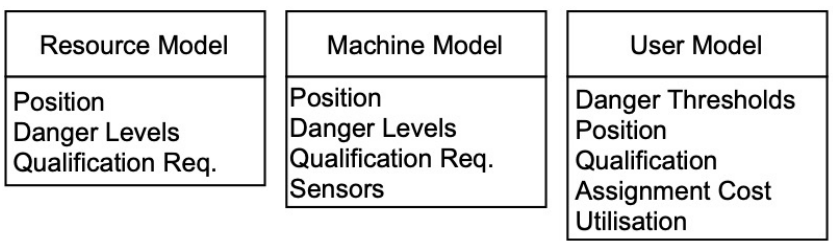
Enabling Contextual AR Processes

Context data models



Contextual information added to the processes that govern how activities should be executed efficiently

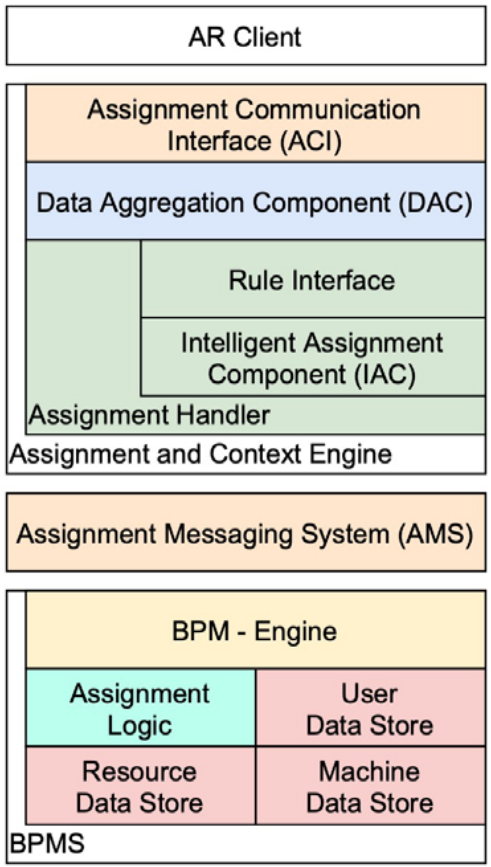
Actor models



Physical entities involved in process execution

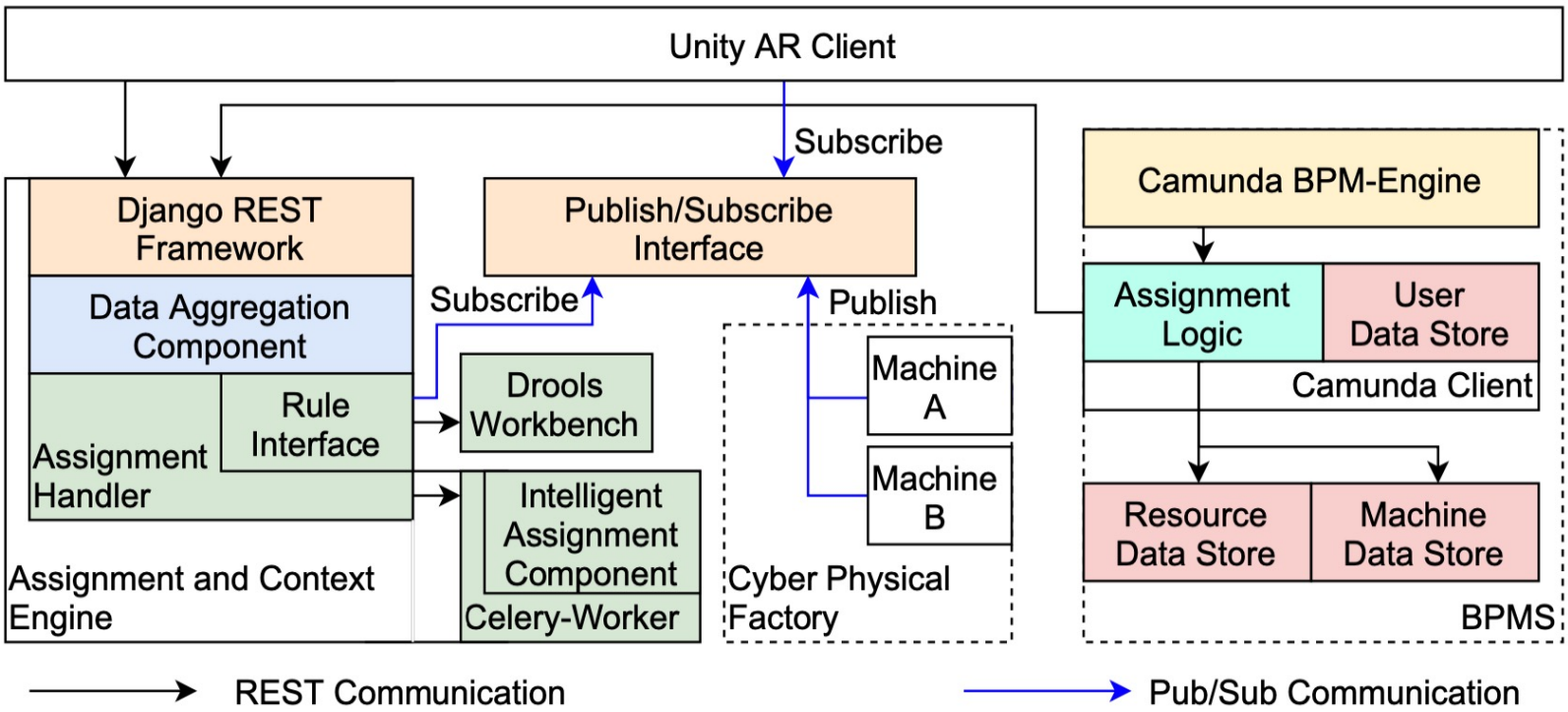
Solution Architecture

- Distributed Services
- Device independent AR Client
  - Support users during task execution
  - Fully functional BPM client
- Assignment and Context Engine with generic APIs
  - Calculate assignments and validate preconditions
  - Provide BPMS independent solution
  - Support easy integration with existing BPMSs
- Assignment Messaging System with high throughput
  - For real-time (sensor) communications
  - Support of common standards
- BPMS with Data Stores for additional machine sensor-based context information



ARPF Implementation Architecture: Camunda & AristaFlow Variants

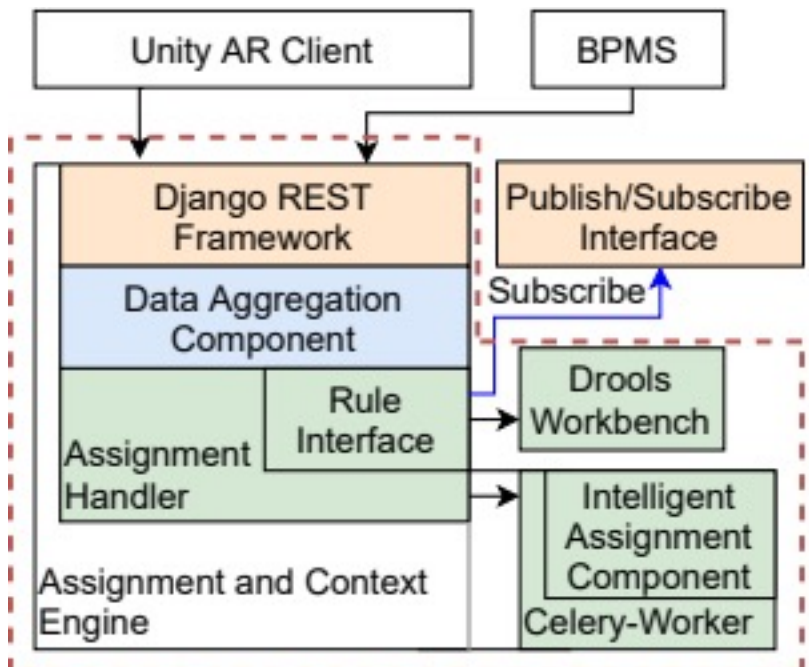
Camunda Variant



ARPF Assignment and Context Engine

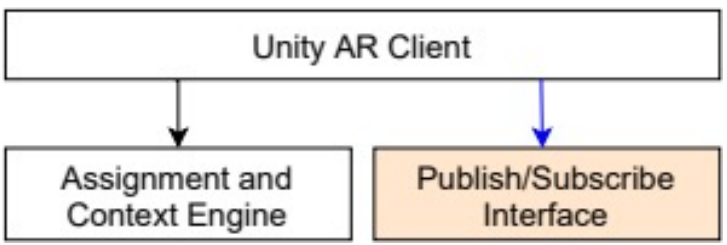
- Core ARPF component
- Calculates optimal assignment via Fuzzy Logic
- Utilizes Celery for multiprocessing
- Bridge between AR Client and BPMS
- BPMS requests assignment calculation via REST
- AR Client requests information and controls process workflow via REST APIs
- Rule Interface allows implementation of external rule engine (e.g., Drools) for user-configurable precondition validation
- Supplies rule engine with latest sensor values via Pub/Sub interface
  - OPC-UA support

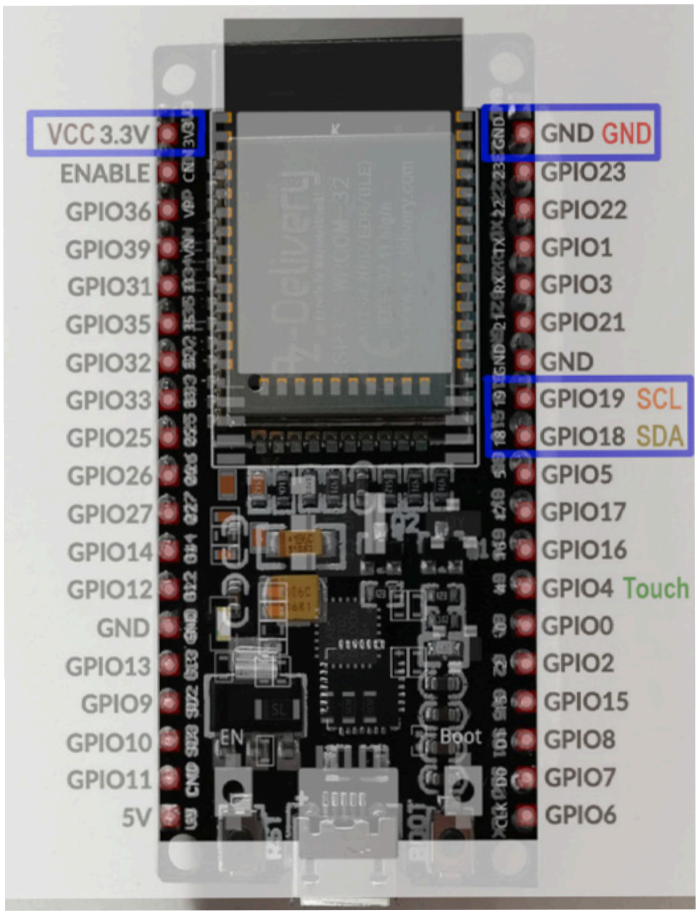
Assignment and Context Engine (red outline)



ARPF Unity AR Client

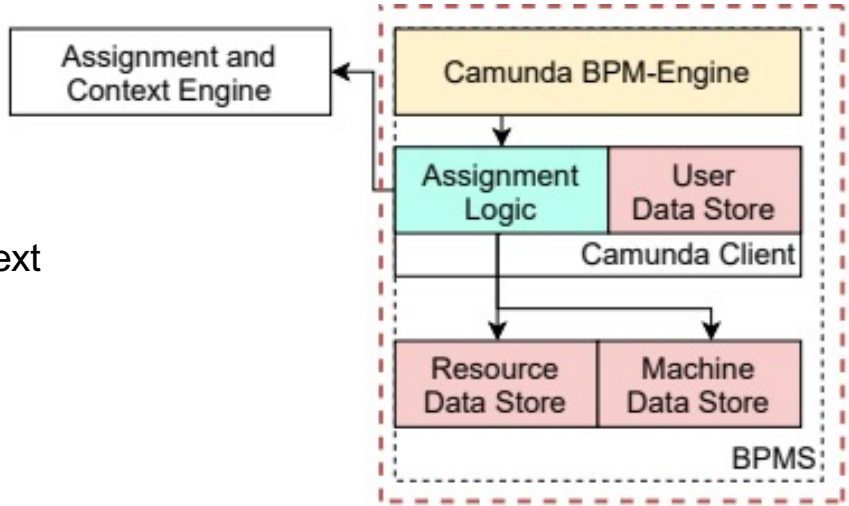
- Common portable AR client software for all AR devices
- Allows complete control of BPM process via AR
- Provides task-specific AR support integrated into AR device (AR goggles, smart tablet, etc.)
- Receives and integrates latest sensor information from task relevant machines via MQTT into AR display

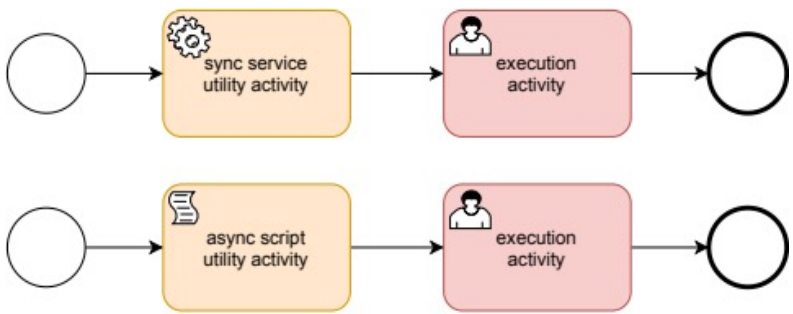




ARPF Architecture: BPMS Integration

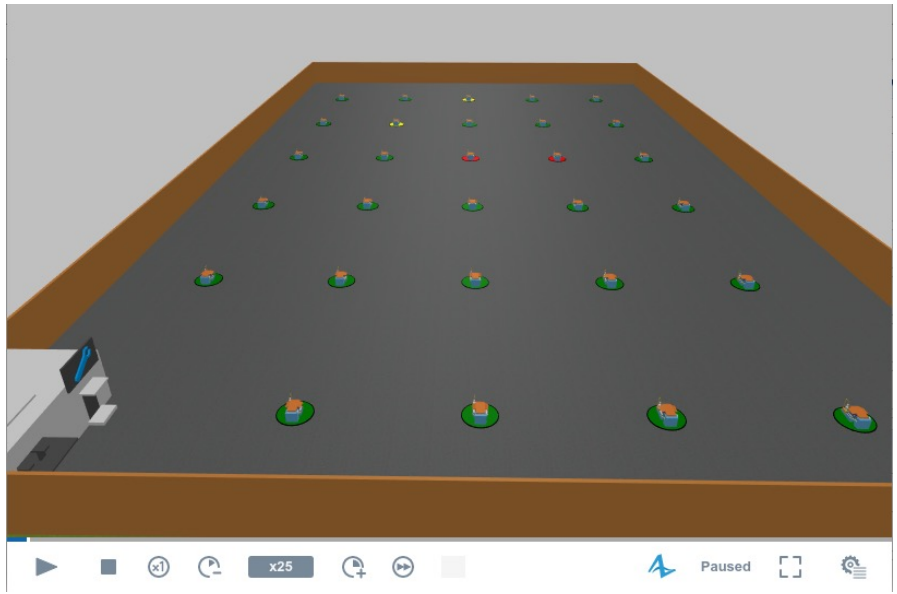
- Optionally extends BPM engine with:
  - User Data Store containing required user context data
  - Resource Data Store containing required resource context data
  - Machine Data Store containing required machine context data
- Requires Assignment Logic to aggregate data and request assignments
- Assignment Logic is called via automatic task in BPM Process template
  - Synchronous assignment request via service task
  - Asynchronous request via script task





Evaluation

- Due to COVID restrictions factory use case was simulated
- Simulation comparison:
  - ARPF-supported BPMS vs. a plain BPMS (Camunda)
- Simulation (with AnyLogic)
  - Repair and maintenance scenario
  - Easy integration in BPMS with REST
  - Interfaces (Camunda, AristaFlow)
  - Reduced downtime for workers
  - Heavily reduced cost through more efficient assignments
  - Reduced downtime for repairs by maintenance
  - Intervals increased due to adjusted prioritization



Simulation Details

- Factory with 21504m^2 so that travel distance makes a difference
- 29 machines requiring maintenance every 16 hours
  - Initial maintenance scheduled 0-16 hours after start of the simulation.
  - Machines had an average breakdown interval of 36 hours.
- 5 workers available to complete these activities
  - 4 internal workers, waiting in a maintenance building in the factory hall
    - Engineering qualifications of 4, 5, 6 and 7
  - 1 external worker (more expensive) waiting 820 meters away.
    - Depicts highly-trained personal often contracted by external service providers.
    - Engineering qualification of 8.
  - Danger thresholds were set to 0.7 for all values.
- If a machine required maintenance or repair:
  - New process instance with the required worker qualification and the machine's position was started.
  - The activity takes between 1 to 3 hours and requires an engineering qualification of 4 for maintenance and 6 for repairs.

	ARP	Camunda
work_time	2103.31	2310.60
idle_time	524.49	396.38
avg_overqual	0.12	0.08
avg_tasks_day	3.52	3.62
violations	0.00	5.12
traveled_distance	9304.40	9502.27
cost	2000.00€	4600.00€
max_avg_underqual	0.00	-0.02
downtime_maintain	439.83	293.14
downtime_repair	218.90	249.32

ARPF-supported BPMS reduced cost, traveled distance, machine repair downtime and prevented any safety regulation violations but had overall higher maintenance downtime

Conclusion

- ARPF is an easy to integrate framework to extend a BPMS for context-aware AR processes
  - Requires minimal changes
  - Generic REST and OPC-UA MQTT interfaces
  - AR integration
- Incorporates extensible context models for Industry 4.0 processes and human resources leveraging AR capabilities
- Fuzzy Logic as core technology for assignment optimization
- Improved efficiencies and process quality and effectiveness achieved via:
  - Intelligent task assignment
  - Context-awareness
  - Customizable assignment criteria and rule validation
  - Integrated AR support