Technology-Enhanced Process Elicitation of Worker Activities in Manufacturing

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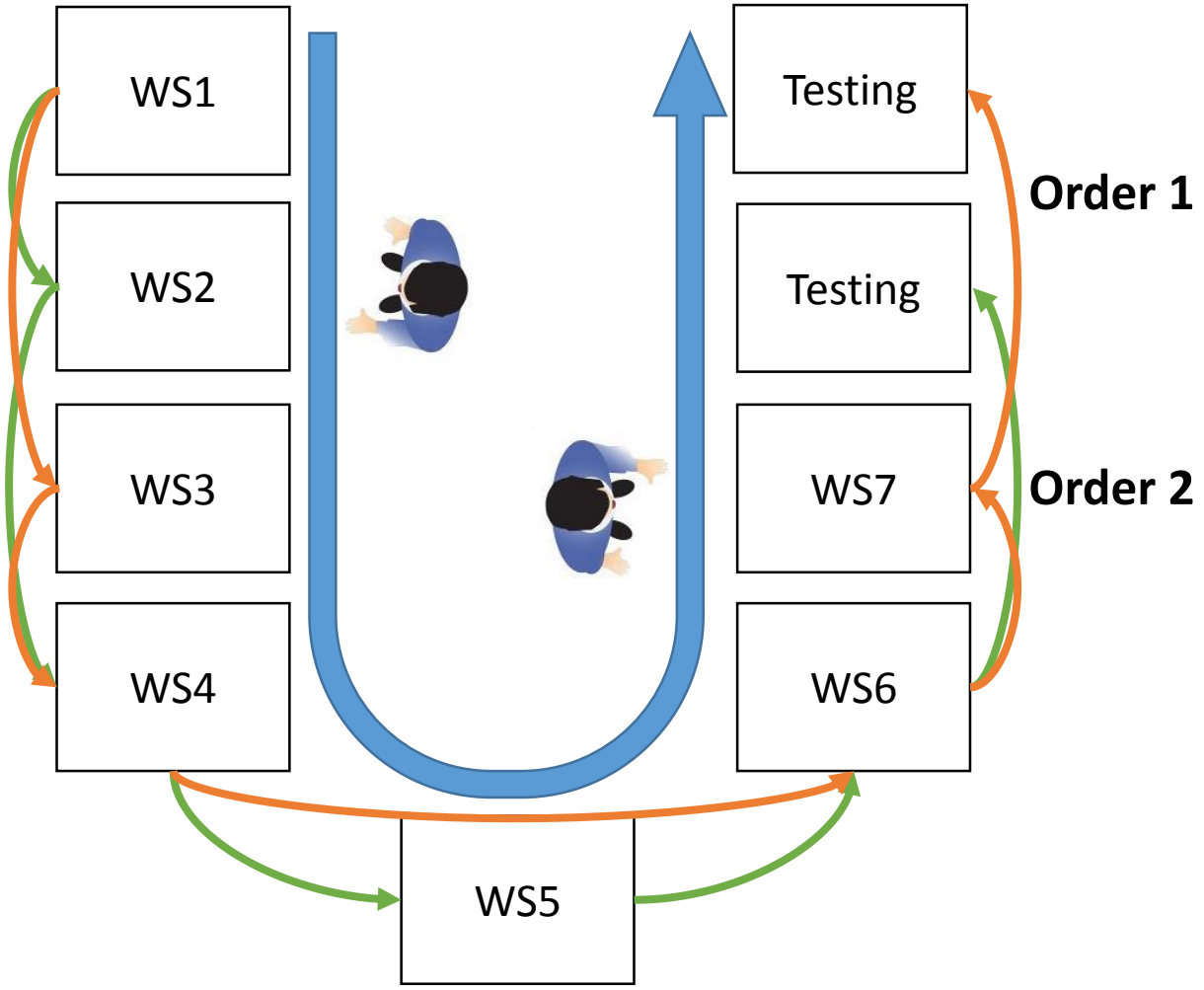
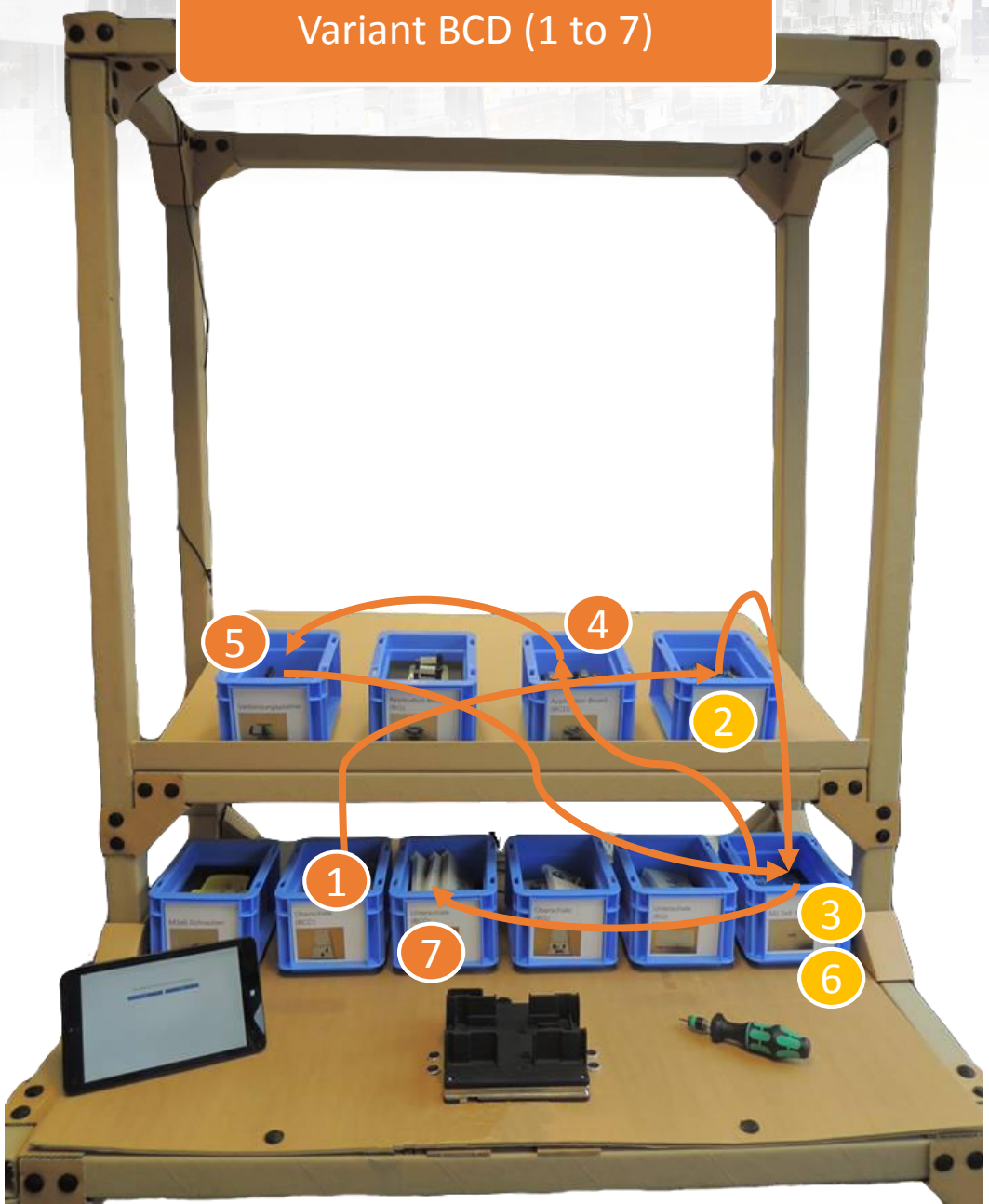
In this work a scenario in the manufacturing domain is addressed: Job shop manufacturing

- Job shop manufacturing:
  - Assembly of *n* orders on *m* assembly workstations
  - One order consists of a sequence of *s* work steps executed on workstations
  - Orders can be assembled multiple times on one workstation or they can be left out
  - Stands in contrast to flow shop manufacturing where on every workstation the same sequence of work steps is executed
- Advantages:
  - High flexibility supporting mass customization and batch size 1
  - Assembly tasks more challenging and less monotonously
- Disadvantages:
  - High stocks and transport effort between assembly workstations
  - Long cycle times and complex production plans

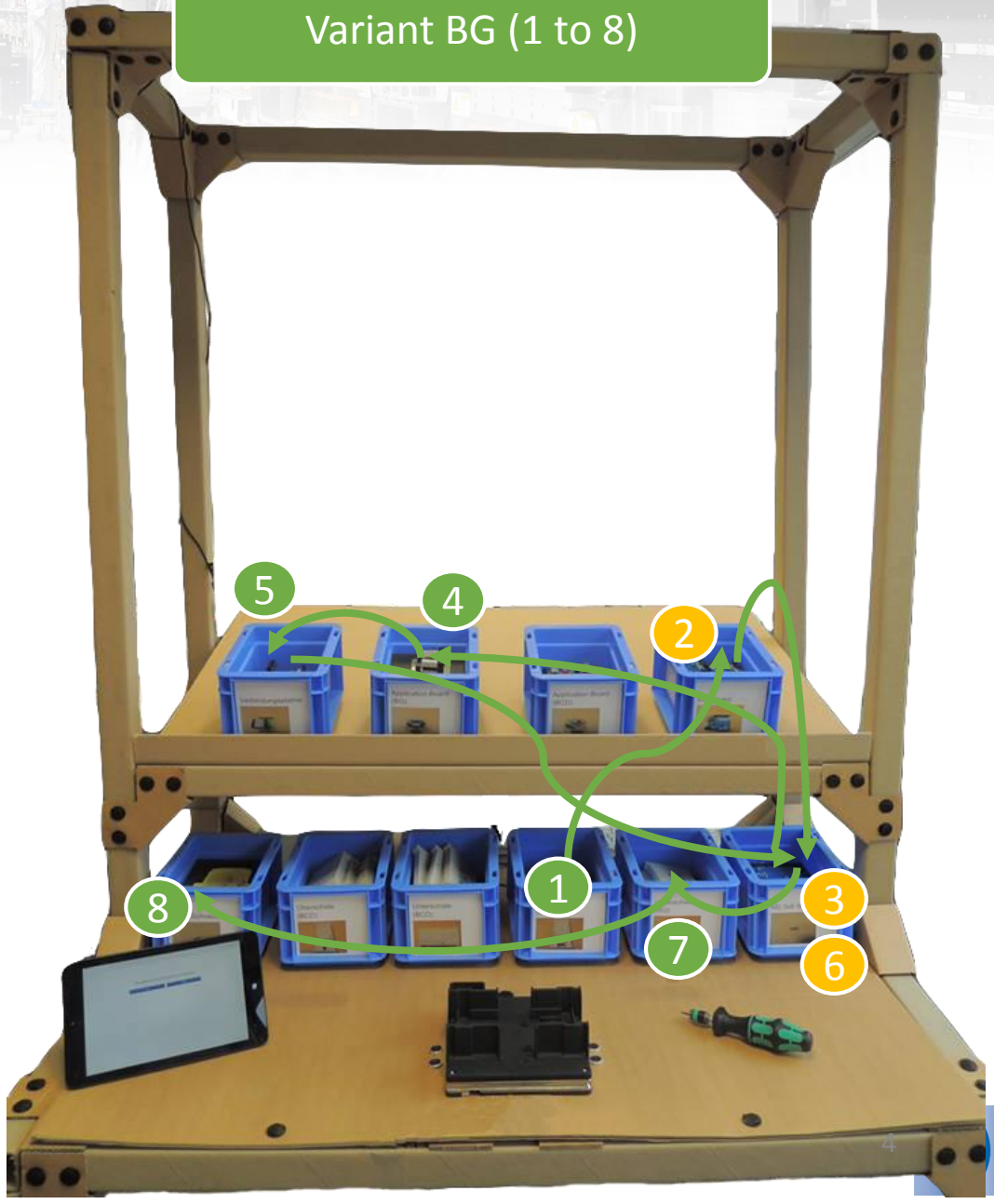
Example: Job shop manufacturing in an U-shaped line layout consisting of multiple assembly workstations (WS)



Variant BCD (1 to 7)



Variant BG (1 to 8)



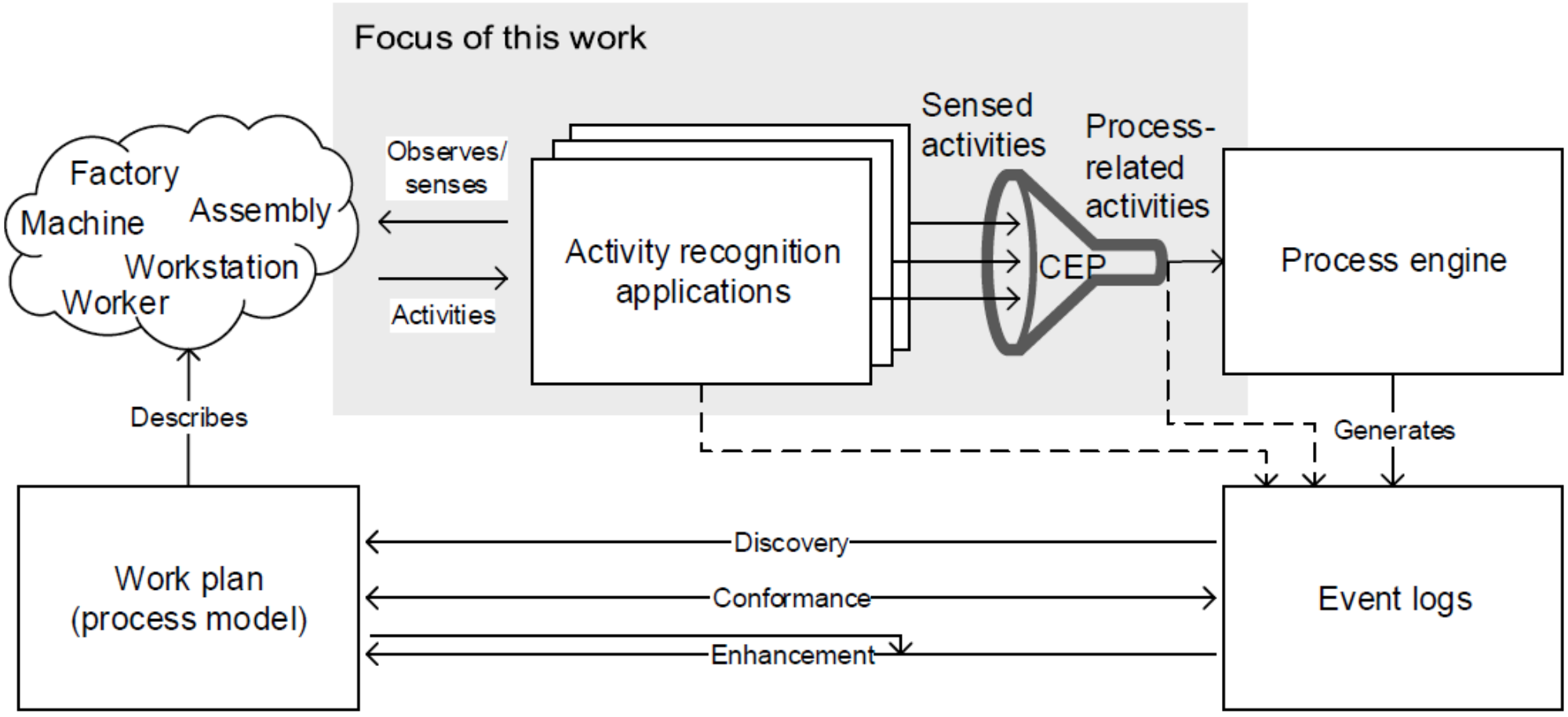
Challenge: Tracking and analyzing these assembly processes to optimize production (planning)

- Production planners and supervisors need accurate information on the assembly process to optimize scheduling and provide support
- Machine data can be gathered and analyzed
- Data on the manual assembly processes is hidden and hard to gather
- Current methods of process elicitation are time consuming and costly
  - Predetermined motion time systems, e.g., REFA and MTM
- Process mining might help, but formalized and complete logs are rare

Approach: Light-weight sensor instrumentation to become aware of the process and things involved

- Goal:
  - Creation of meaningful event logs
  - Event to process correlation
- Requirements:
  - Light-weight instrumentation to support temporary observations
  - No restriction of the worker’s motion
  - Low acquisition and operating costs
  - Appropriate for manufacturing environments
  - Integration in existing event streams

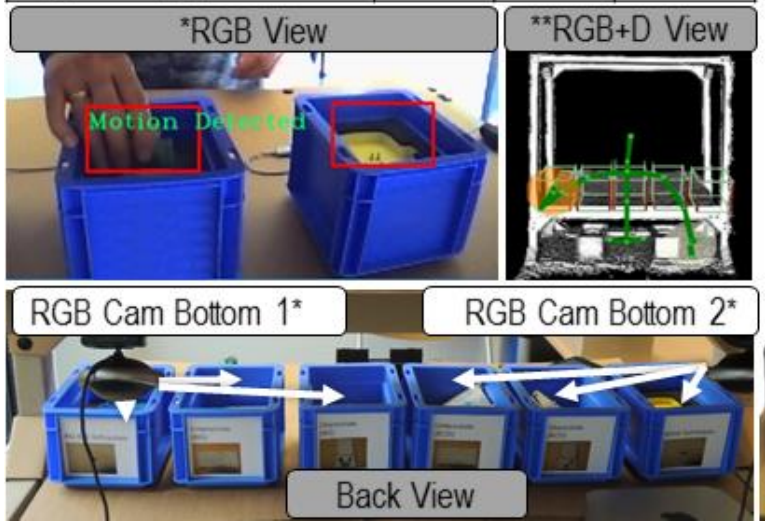
Solution (1/5): Sensing real world processes and creating a digital representation

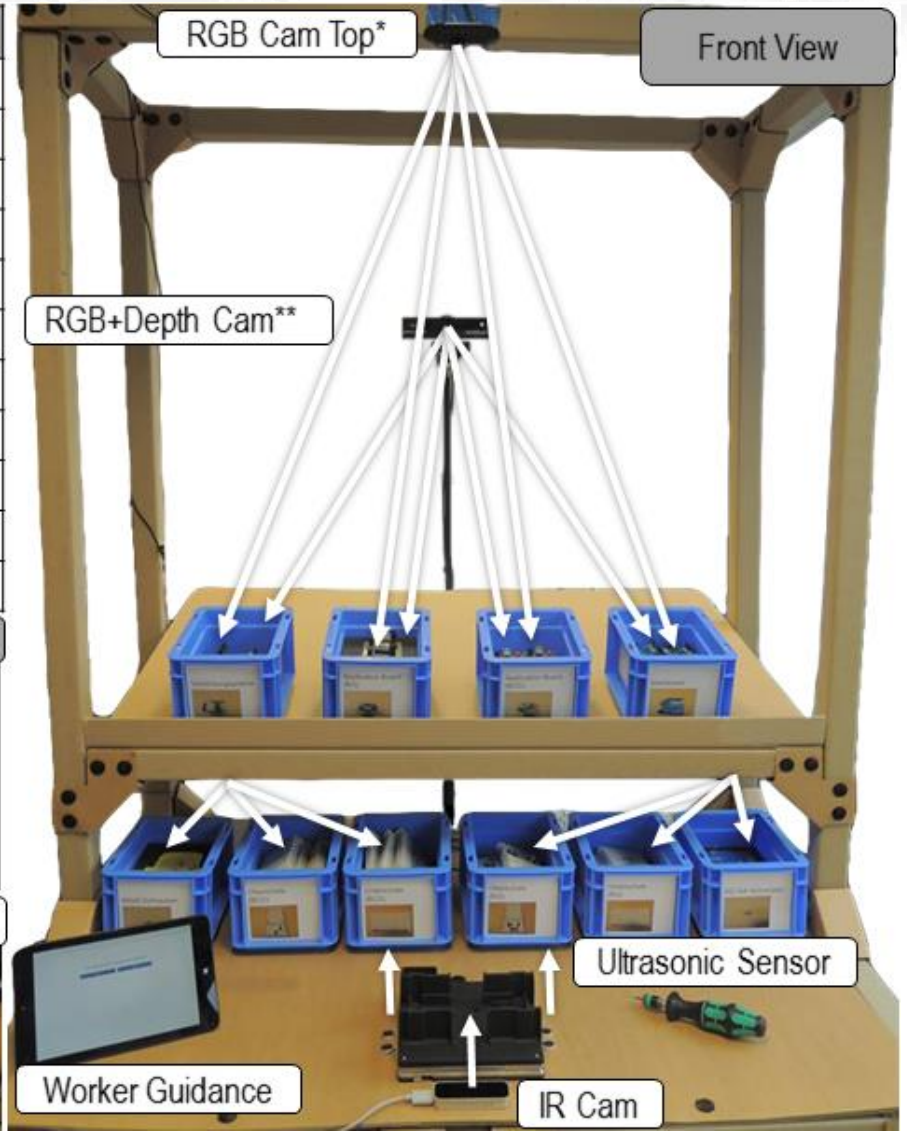


 Extension of Fig. in W. M. P. van der Aalst, Process Mining: Data Science in Action. 2nd ed. Heidelberg: Springer, 2016.

Solution (2/5): Laboratory setting

Material in SLC	BG	BCD	Activity
BCD_Top_Casing	-	Task 1	Mount
BG_Top_Casing	Task 1	-	Mount
Mainboard	Task 2	Task 2	Insert
Small_Screws (x2)	Task 3	Task 3	Screw
BCD_Application_Board	-	Task 4	Insert
BG_Application_Board	Task 4	-	Insert
Connecting_Board	Task 5	Task 5	Plug
Small_Screws (x2)	Task 6	Task 6	Screw
BCD_Bottom_Casing	-	Task 7	Clip
BG_Bottom_Casing	Task 7	-	Fit
Big_Screws (x4)	Task 8	-	Screw





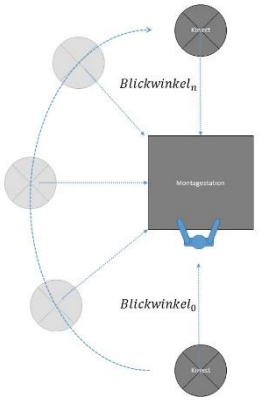
- Sensors:
  - 3 RGB cams
  - 1 depth cam
  - 1 infrared cam
  - 2 ultrasonic
- Event processing:
  - Bus: MQTT
  - CEP: Apama
- Product:
  - 2 variants: BG/BCD
  - 8/7 tasks
  - 10 materials
  - 3 variant specific mat.

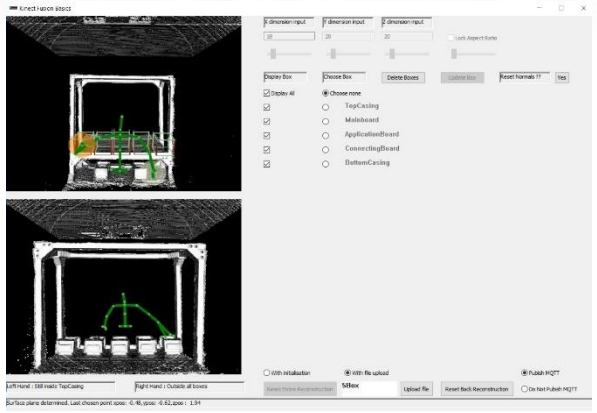
Solution (3/5): Activity recognition via RGB cameras (web cams)

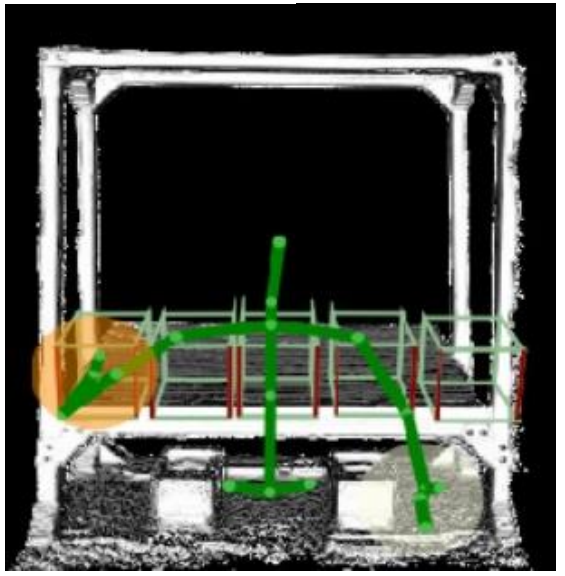
- Definition of activity zones through editor interface
- Flexible labeling of these zones
- Activity detection with web cams: 30fps, algorithm at 20-25fps
- Background subtraction based on continuously updated Gaussian mixture model: last 500 frames
- Supports the filtering of shadows
- Sensitivity is configurable

Solution (4/5): Activity recognition via RGB+D cameras (Kinect)

- Definition of 3D activity zones through editor interface
- Flexible labeling of these zones
- Tracking of 25 joints at the rate of ca. 30fps
- The hand position from Kinect forms the center of a 3D activity sphere of 10cm radius
- The intersection of this activity sphere with a 3D activity zone surrounding an observed object is the trigger for activity detection
- The occlusion of the body and the viewing angle of the Kinect are factors that affect accuracy and need to be carefully handled







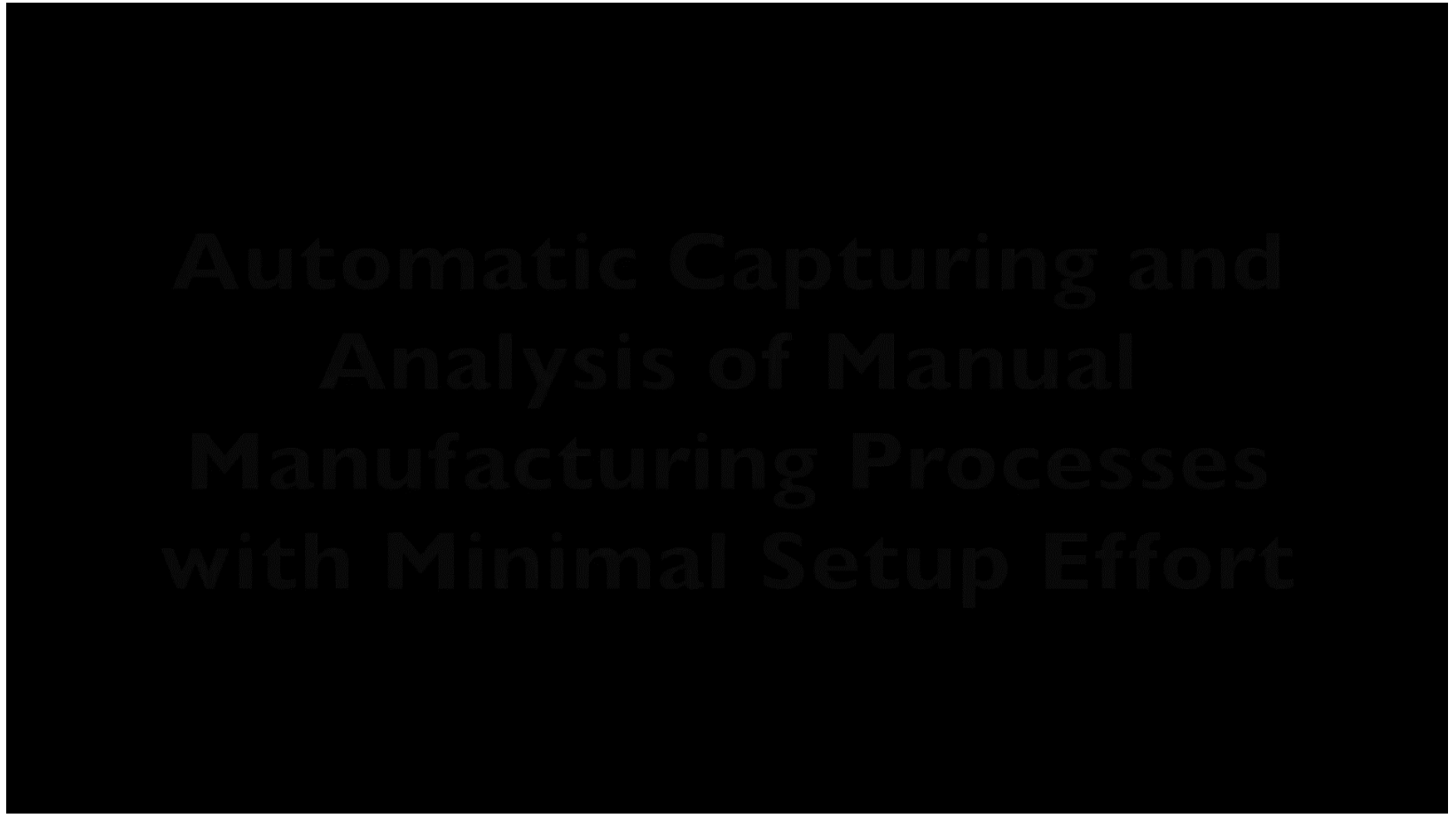
Solution (5/5): Work step composition

```
event ManualWorkStep {
    string topic;
    integer timestamp;
    dictionary<string,string> payload;
}
```

```
inputs {
    ManualWorkStep() key timestamp
    within 20 sec;
}
```

```
find ManualWorkStep:e1 -> ManualWorkStep:e2
where e1.topic =“#/ApplicationBoard/In“ and e2.topic =“#/ApplicationBoard/Out“
  without  (e3.topic =“#/ApplicationBoard/Out“ {
        // matching found => create payload
        integer duration = e2.timestamp – e1.timestamp;
        dictionary<string,string> payload := {
                “material:STRING“: “ApplicationBoard“,
                “activity:STRING“: “Application board supply“,
                “timestamp:NUMBER“: e2.payload[“timestamp:NUMBER“],
                “duration:NUMBER“: duration.toString()
        };
        send ExecutedTask(“Stations/1/ApplicationBoard/Grasp“, payload) to “mqttChannel“; }
```

System in action: Carton prototyping workstation instrumented with sensors



Experiment (1/2): Experimental setting

- 12 participants (students and campus staff)
- Each participant assembled 4 products, 2 of each variant (BCD, BG)
- Instructions (worker guidance) were provided on an 8 inch tablet
- Ground truth was captured on video that was annotated afterwards
- Best matching sensor event was found calculating the best match based on a simple undirected weighted (time) bipartite graph

Experiment (2/2): Results and discussion

- Result of the cameras detecting access to material boxes
  - RGB camera delivered a median F-score of 0.83
  - RGB+D camera delivered a median F-score of 0.56
- Effects on the detection
  - Anomalies: miss picks, moving hand over boxes while searching material
  - Physical setup:
    - camera angle and position (visibility/occlusion)
    - light conditions/shadows
    - shock resistance (carton workstation)
    - camera device (customer electronics)

Conclusion: Next steps towards a cyber-physical business process management

What has been done:

- Implementation and evaluation of an artifact supporting process elicitation in manual assembly systems in job shop manufacturing
- Setup in a laboratory setting and its evaluation proofed the concept

What we're going to do in the future:

- Addressing the side effects and improving precision
- Adding detection of material parts
- Testing process mining methods on the event logs created: check conformance, enhance processes, and provide operational support