Context-aware optimization strategies for universal application in smart building energy management

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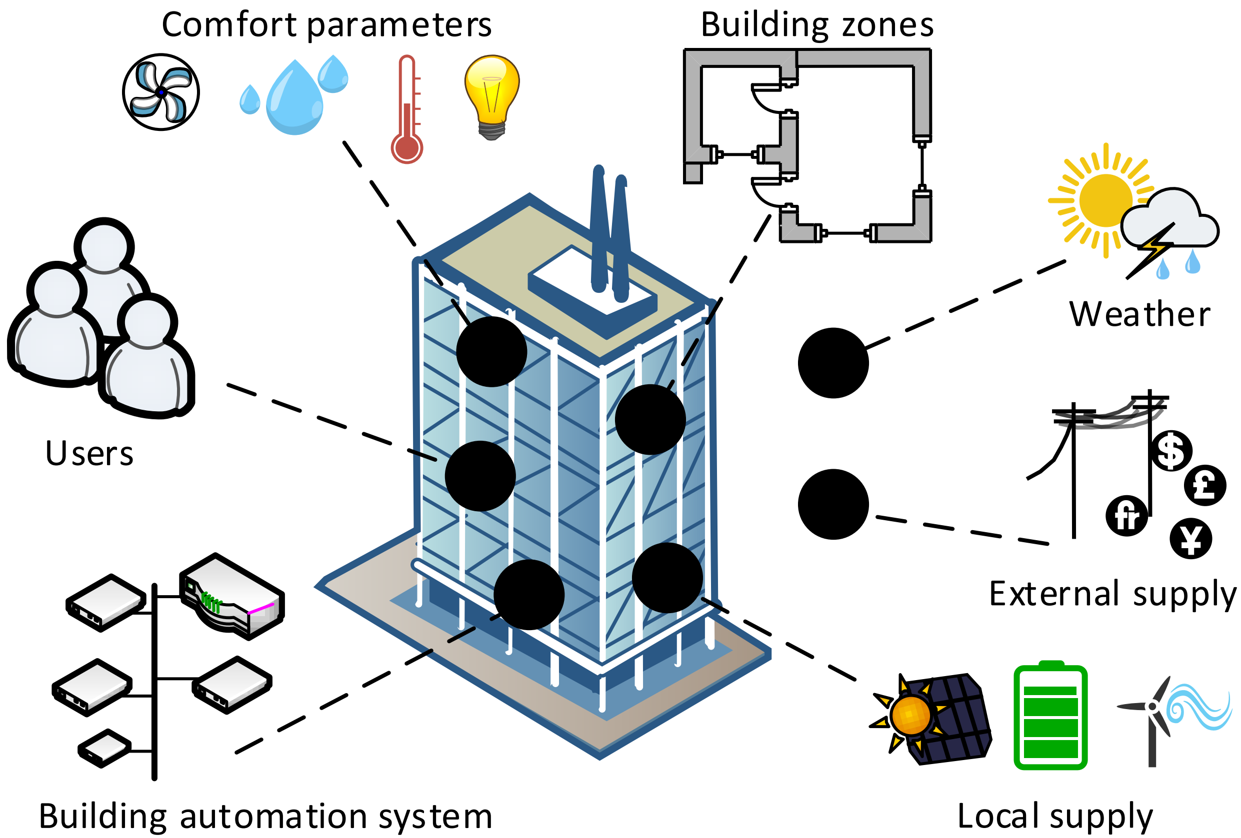
Motivation

- **Tackling energy needs of buildings**
  - Building automation systems as key enablers
  - Forward planning of energy-efficient schedules

- **Requirements for building energy management systems**
  - Independent of building types
  - Support of different equipment
  - Integration of decentralized energy resources
  - Easy design and implementation
  - Little need for training and setup

Motivation



$$\rightarrow \quad min\sum_{t=1}^{n} F_t \quad \text{where} \quad F_t = \omega \cdot c_t + (1-\omega) \cdot e_t$$

Motivation

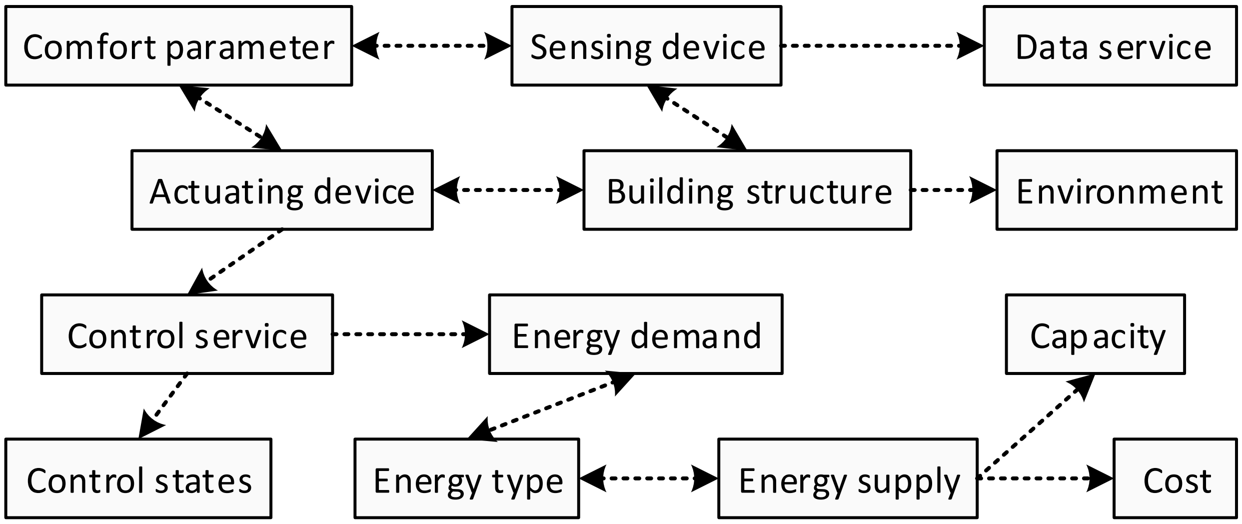
- **Various approaches in literature, but…**
  - Often limited reusability in other settings
  - Specialization on certain buildings, technologies, domains
  - Lack of machine-readable semantics
  - Hardcoded expert knowledge

- **Context-aware optimization strategies**
  - Strategies on top of an ontology
  - Decoupling from underlying technologies
  - Embedding into common metaheuristics

Contents

Ontological basis

- Analysis of related work (ThinkHome, CTRLont, ifcOWL, …)
- Abstract modeling of machine-readable semantics
- Reuse of existing ontology
- Main concepts and relationships:

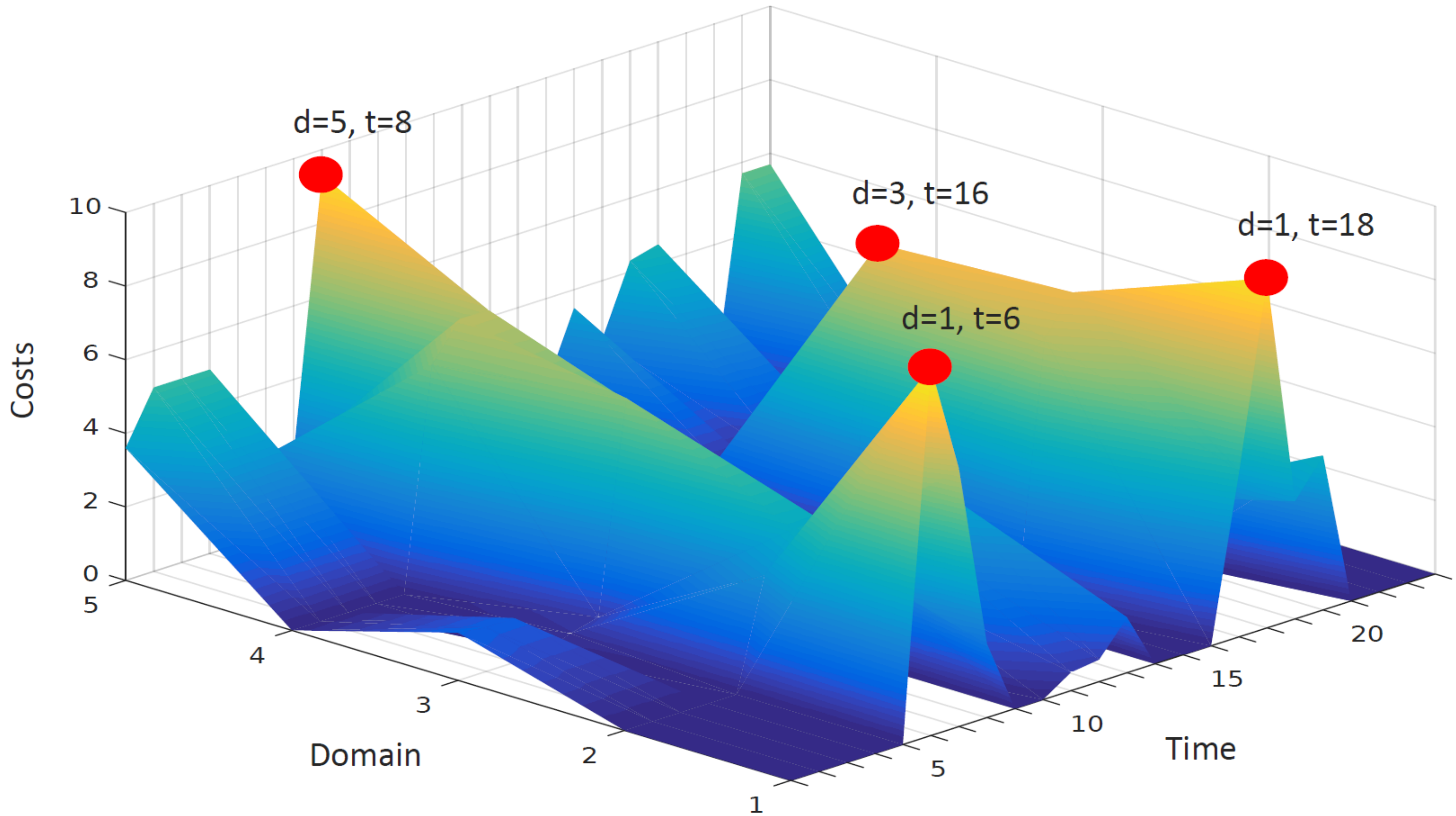


Optimization strategies

1. **Subproblem identification**
   - Divide and conquer paradigm
   - Fitness evaluation as basis
   - Separation of costs into atomic components
     - Time slots (optimization period)
     - Cost domains (comfort costs, energy costs)
   - Prioritization of components
     - High costs with higher selection probability
     - Earlier components with higher probability
   - Cost-proportional selection

Optimization strategies

1. **Subproblem identification**

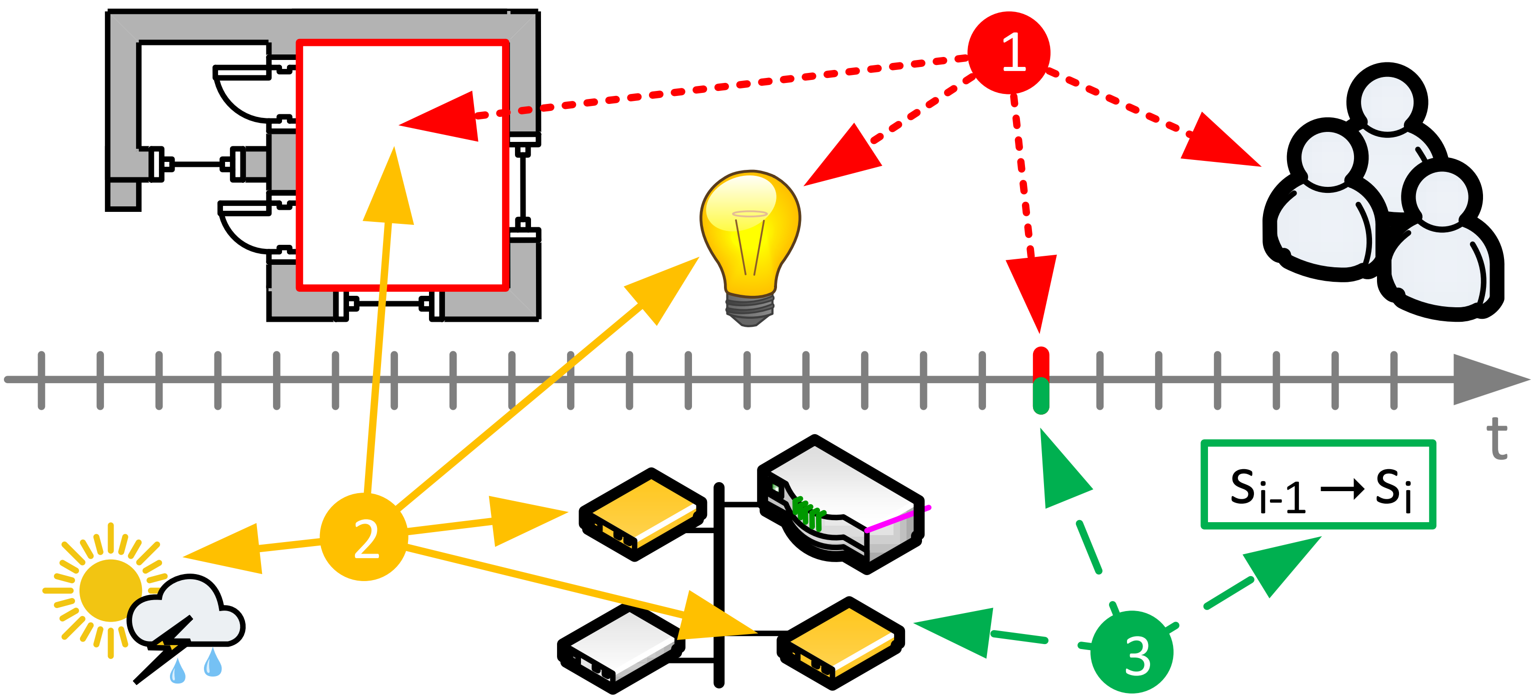


Optimization strategies

2. **Partial modification**
   - Conquer selected subproblem
     - Substitute devices
     - Use storage flexibility
     - Reduce comfort over-fulfillment
     - Consider external influences
     - Consider temporal dynamics of processes
   - Modification based on nested neighborhoods
     - Neighbor solutions near the problem domain
     - Moves are device state changes

Optimization strategies

2. Partial modification



Optimization strategies

3. Impact assessment

- Learn from made experiences
- Interpret impacts of schedule modifications
- Write inferred knowledge back into the ontology
  - Specific rules
  - Basic relations
  - Generic rules

$$\delta_x = \begin{cases} \uparrow & \text{if } s_{i-1} < s_i \\ \downarrow & \text{if } s_{i-1} > s_i \end{cases}$$

$$\delta_d = \begin{cases} \uparrow & \text{if } \operatorname{sgn}(\Delta_{d,t}) = 1 \\ \downarrow & \text{if } \operatorname{sgn}(\Delta_{d,t}) = -1 \end{cases}$$

Embedding into metaheuristics

- Heuristic problem solving for hard problems
- Integration of atomic strategies
  - Solution shaking, intelligent search, randomized mutation
- Single solution metaheuristics
  - Local search, VND, GVNS, …
- Population-based metaheuristics
  - Genetic algorithm, ant colony optimization, …

Evaluation

Algorithm 1 Extended variable neighborhood descent *(S)*

```
while stopping criteria not satisfied do
    p ← identify subproblem (S)
    k_max ← get neighborhoods (S, p)
    k ← 1
    while k < k_max do
        while no improvement & neighbors unvisited do
            S′ ← run partial modification (S, k, p)
            assess impacts (S, S′)
        end while
        if f(S′) < f(S) then
            S ← S′
            k ← 1
        else
            k ← k + 1
        end if
    end while
end while
return S
```

Evaluation

- Analysis of basic principles and optimization behavior
- Definition of case studies
  - Simple settings
  - Multiple domains
  - PV production
  - Electric vehicles
  - …
- Assessment of impacts
- Behavior observation

Task	Tradeoff between privacy, brightness, and energy consumption
Resources	Blind (0% $\prec$ 100%, 0% = up), lamp (0% $\prec$ 100%, 0% = off)
Zones	Home office
Influences	Occupancy (0/1), sunlight (lx), energy tariff (€)
Domains	Electric energy (kWh), brightness (lx), privacy (sat/unsat)
Initial situation	High priority on privacy, lamp always on (100%), blind always up (0%), privacy required in the evening
Observed behavior	First, high costs of privacy are tackled. Blind is shut and light is turned on although sun is shining. Energy costs in these slots are lower than comfort deviation costs. During day, lamp is turned off if sunlight is enough.
Example rules	$s_{lamp} \uparrow \Rightarrow d_{brightness} \uparrow$ $s_{blind} \uparrow \Rightarrow d_{privacy} \uparrow$

Evaluation

- **Benefits**
  - Continuous growth of behavior knowledge
  - Faster convergence towards suitable solutions
  - Abstract view on optimization
  - Separation of semantics and implementation
- **Issues**
  - Priorities for randomization
  - Scaling factors for fitness conversion
  - Termination thresholds
  - Diversity for population-based heuristics

Conclusion

- **Context-aware optimization strategies**
  - Ontology for semantic modeling
  - Universal optimization strategies
  - Integration of strategies into metaheuristics
  - Case study-based evaluation
- **Outlook**
  - Implementation of other metaheuristics
  - Comparison of implementations
  - Consideration of smart grid flexibility trading
  - Analysis regarding limits of applicability

Thank you!