Toward Systematic Conveying of Architecture Design Knowledge for Self-Adaptive Systems

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Pole placement?

Self-Adaptive Systems

Effective solutions highly tailored to specific problems

Lack of support for well-informed trade-off analysis

Large design/solution space
Pole placement?

Root locus?

Self-Adaptive Systems

Highly specialized domain

Lack of support for well-informed trade-off analysis

Effective solutions highly tailored to specific problems

Large design/solution space
What am I supposed to do with all these stuff?
DuSE = Domain-specific design spaces + Quality metrics of automatically generated candidate architectures + A multi-objective optimization approach
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SA:DuSE = DuSE instance (design space) for the Self-Adaptive Systems domain
SA:DuSE Design Space

**DD₁**: Control Law

**DD₂**: Tuning Approach

**DD₃**: Control Adaptation

**DD₄**: MAPE Deployment
## SA:DuSE Design Space

### DD₁: Control Law
- VP11: Proportional
- VP12: Proportional-Integral
- VP13: Proportional-Integral-Derivative
- VP14: Static State Feedback
- VP15: Precompensated Static State Feedback
- VP16: Dynamic State Feedback

### DD₂: Tuning Approach
- VP21: Chien-Hrones-Reswick, 0 OS, Dist. Rejection
- VP22: Chien-Hrones-Reswick, 0 OS, Ref. Tracking
- VP23: Chien-Hrones-Reswick, 20 OS, Dist. Rejection
- VP24: Chien-Hrones-Reswick, 20 OS, Ref. Tracking
- VP25: Ziegler-Nichols
- VP26: Cohen-Coon
- VP27: Linear Quadratic Regulator

### DD₃: Control Adaptation
- VP31: Fixed Gain (no adaptation)
- VP32: Gain Scheduling
- VP33: Model Identification Adaptation Control

### DD₄: MAPE Deployment
- VP41: Global Control
- VP42: Local Control + Shared Reference
- VP43: Local Control + Shared Error
SA:DuSE Quality Metrics

- $M_1$: Control Overhead
- $M_2$: Average Settling Time
- $M_3$: Average Maximum Overshoot
- $M_4$: Control Robustness
# SA:DuSE Quality Metrics

## $M_1$: Control Overhead

$$ME_1 = \frac{\text{allOwnedElements()} \rightarrow \text{selectAsType}(\text{QController}) \rightarrow \text{collect} \left( \text{overhead}() \right) \rightarrow \text{sum}()}{\text{allOwnedElements()} \rightarrow \text{selectAsType}(\text{QController}) \rightarrow \text{size}()}$$

; $\text{QController}: \text{overhead}()$ increasingly penalizes $\text{VP}_{32}$, $\text{VP}_{33}$, $\text{VP}_{41}$ and $\text{VP}_{43}$

## $M_2$: Average Settling Time

$$ME_2 = \frac{\text{allOwnedElements()} \rightarrow \text{selectAsType}(\text{QParametricController}) \rightarrow \text{sum}(\text{stime}())}{\text{allOwnedElements()} \rightarrow \text{selectAsType}(\text{QParametricController}) \rightarrow \text{size}()}$$

; where $\text{QParametricController}: \text{stime}() = \frac{-4}{\log(\max|p|)}$

; and $\max|p|$ is the magnitude of the largest closed-loop pole

## $M_3$: Average Maximum Overshoot

$$ME_3 = \frac{\text{allOwnedElements()} \rightarrow \text{selectAsType}(\text{QParametricController}) \rightarrow \text{sum}(\text{maxOS}())}{\text{allOwnedElements()} \rightarrow \text{selectAsType}(\text{QParametricController}) \rightarrow \text{size}()}$$

; where $\text{QParametricController}: \text{maxOS}() = \begin{cases} 0; \text{real dominant pole } p_1 \geq 0 \\ |p_1|; \text{real dominant pole } p_1 < 0 \\ r^{\pi/|\theta|}; \text{dominant poles } p_1, p_2 = r e^{\pm j \theta} \end{cases}$

## $M_4$: Control Robustness

$$ME_4 = \frac{\text{allOwnedElements()} \rightarrow \text{selectAsType}(\text{QController}) \rightarrow \text{collect} \left( \text{robustness}() \right) \rightarrow \text{sum}()}{\text{allOwnedElements()} \rightarrow \text{selectAsType}(\text{QController}) \rightarrow \text{size}()}$$

; $\text{QController}: \text{robustness}()$ increasingly penalizes $\text{VP}_{31}$ and $\text{VP}_{32}$. 
DuSE Optimization

3 loci of decision -> 54,010,152 candidates
4 loci of decision -> 20,415,837,000 candidates
DuSE Optimization

3 loci of decision -> 54,010,152 candidates
4 loci of decision -> 20,415,837,000 candidates

A search-based approach enables effective design space exploration and helps preventing false intuition and technology bias

```plaintext
1: procedure DUSE_OPT(i, di)
2:   ▶ i = input model; di = DuSE instance
3:   s ← globalSettings()
4:   dii ← createAppDSInstance(i, di)
5:   p ← randomPopulation(dii, s.populationSize)
6:   curIteration ← 0
7:   while curIteration ≤ s.maxIterations do
8:     p ← nsga2Rank(p, dii, s.populationSize)
9:     p ← p ∪ nsga2Mate(p, s.offspringSize)
10:    curIteration ← curIteration + 1
11:   end while
12:  return nsga2highestParetoRank(p)
13:  end procedure
```
Tool Support (DuSE-MT)
Case Study

Cloud-based media encoding service

Three loci of decision (controllable components)

Annotations from Qemu + Hadoop + CloudStack experiments

Control goal: enforce encoding throughput
Findings
Conclusion

Contributions

Systematic gathering of architecture design knowledge in the field of Self-Adaptive Systems

A search-based approach for endowing architectures with self-adaptative behaviour and explicit support for well-informed design trade-off analysis

A supporting tool (DuSE-MT)
**Conclusion**

**Contributions**
- Systematic gathering of architecture design knowledge in the field of Self-Adaptive Systems
- A search-based approach for endowing architectures with self-adaptative behaviour and explicit support for well-informed design trade-off analysis
- A supporting tool (DuSE-MT)

**Limitations**
- Requires an initial annotated architectural model
- No guaranteed optimality (local-optimal Pareto fronts)
- Still requires *a posteriori* preference articulation

**Current & Future Work**
- Second case study
- Resulting Parent front evaluation (indicators)
- From Design Spaces to Design Theories