サービスコンピューティング研究会

Robust Workflows by Applying Functional Clustering on Multi-Objective Service Composition
(多目的のサービス合成における，機能クラスタリングの適用によるロバストなワークフローの構築)

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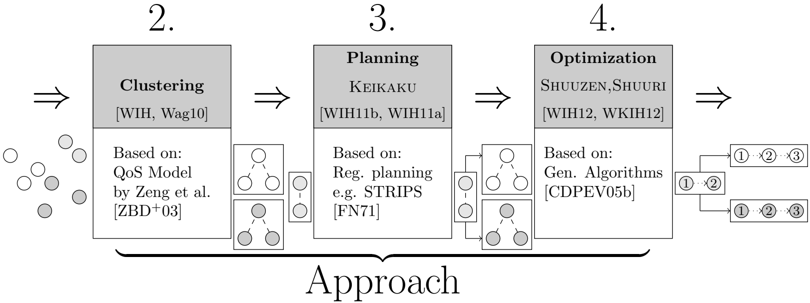
Honiden Laboratory

平成25年3月15日

1. Introduction

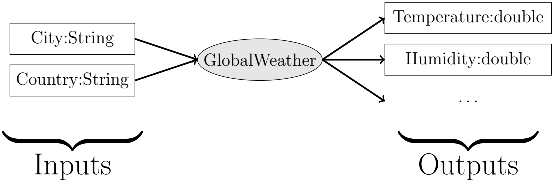


5. Summary

Service-Oriented Computing

- Services **encapsulate** business logic
- **Loosely**-coupled, **flexible** components
- Interface description documents:
  1. **Functional** IOPE interface
     - ⇒ **I**nputs, **O**utputs, **P**reconditions, **E**ffects
     - ⇒ Semantics: associate concepts to IOPE
  2. **Non-functional** Service-Level Agreement
     - ⇒ Contains Quality-of-Service (QoS)
     - ⇒ Specified by the provider
     - ⇒ Example: price, response time, ...

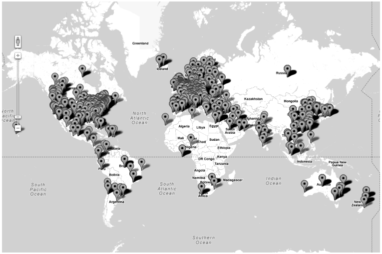
GlobalWeather service[1]:



[1] `http://www.webservicex.net/globalweather.asmx`

Services in Practice

- Web services: **20,000** [ZZL10] to **30,000** [Tec12]:



- Successfully applied in **many companies**, such as eBay, Amazon [DPPS⁺08, ZDN12], IBM, DreamWorks, HP [ZDN12], Winterthur, Deutsche Post [KBS04]
  - **Credit Suisse** [Mur11]: "All applications on the Swiss Platform offer and/or consume services"
    - ⇒ 1000 services, 400Mio. calls per month.
    - ⇒ Research challenges: existence of 1000s of services, fault-tolerant design, varying service interfaces
  - **Twitter API** invoked 15 billion times a day, **Google** and **Facebook** 5 billion [LG11]

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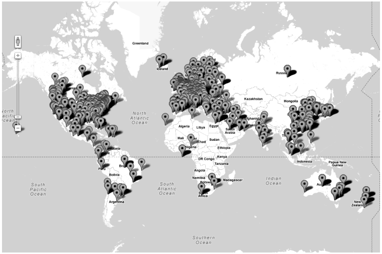

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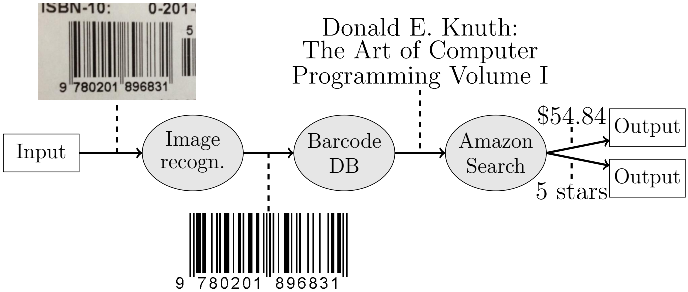
Service Composition

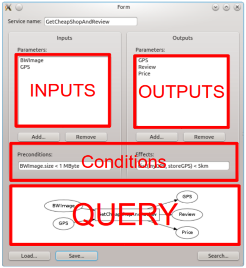
- **Key benefit** of services: generate new software
  - Services are arranged in workflows, described with BPEL
  - Executed with BPEL engines → no additional code necessary (in theory)

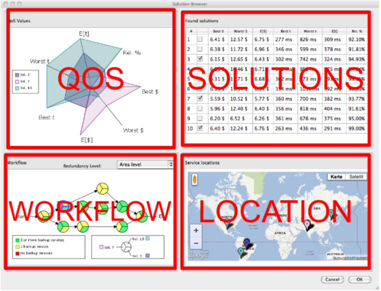
⇒ **Goal**: Automatic service composition



Scenario: Mobile Service Store

- **User** of the system: service broker
- Combines **existing services** with his/her **own** services
- **Interesting services**: database access (IP to GPS), changing data (weather, stocks), data-intensive (genome alignment)





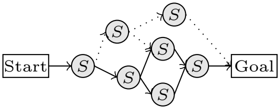
Steps:

1. Definition of the **parameters** and **QoS preferences**
2. System **proposes** set of **solutions**
3. User **compares** the **solutions**, **picks** one
4. Composite service is **registered** at service directory

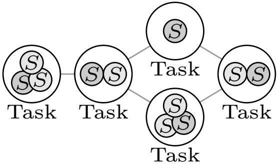
Service Composition Approaches

Two main approaches:

1. **Planning** [WPS+03, KG06, LKS08]
   - Starts from scratch
   - Applies AI planning tool
   - **Drawbacks:**
     - ⇒ **Scalability** issues: $\mathcal{O}(S^W)$ (**C1**)
     - ⇒ Insufficient coverage of **QoS aspects** (Challenge **C2**)



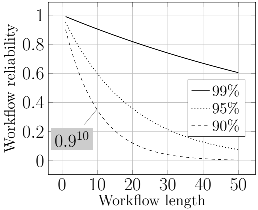
2. **Selection** [ZBD+03, CDPEV05a, YZL07]
   - Refines workflow templates
   - Faster, QoS-aware: T^W, $T \ll S$
   - **Drawbacks**:
     - ⇒ No flexibility ⇒ **template required** (**C3**)
     - ⇒ Simplified modeling by Zeng [ZBD+03]: Services in task are assumed to be equal (**C4**)



Service Composition Approaches

Both fail to achieve an insufficient reliability:

- With **growing** workflow **length**, service **crashes** become more likely
- Most related approaches rely on **ad-hoc replanning** during runtime:
  - Works **only** if **suitable backup** services exist
  - Might cause **additional costs** for un-doing certain actions
  - No predictability:
    - ⇒ Backup services have **worse QoS**
    - ⇒ **Response time** and, potentially, **price** of the failed service(s) increase the costs
- Constitutes **challenge C5**

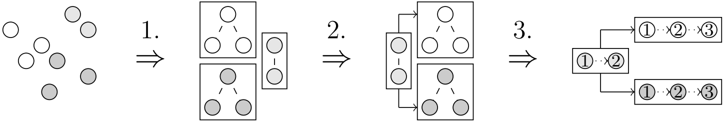


$$Rel(WF) = \prod_{S \in WF} Rel(S)$$

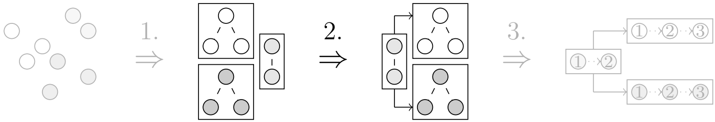
$$\Rightarrow 0.9^{10} \approx 0.35$$

Research Theme

- **Observation**: for a certain purpose (e.g. book hotel room), multiple services exist
  - Developed **independently**
  - **Functionally similar** but not equivalent
  - **Naïve integration** of planning with selection **infeasible**
    - ⇒ Requires identical functional interfaces
    - ⇒ Planning has to consider QoS
- **Our proposal**: integrate planning with selection by
  1. **Clustering** the existing services
  2. **Planning** to create templates, not workflows
  3. **Selection** to refine templates to workflows

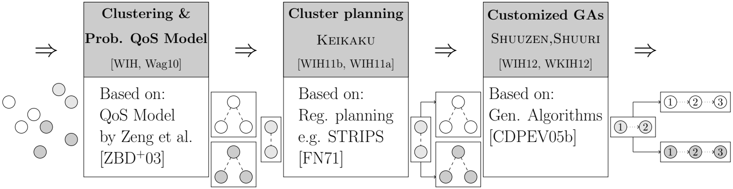


Research Theme



- **Problems**:
  - Planning with clusters is "**fuzzy**": **which** clusters can be **combined**?
  - How to compute **templates** that contain services **with "promising"** QoS?
- **Advantages**:
  - ⇒ Addresses challenges **C2** and **C3**
    - Planning (2.) generates functional template ⇒ flexible (C3)
    - Selection (3.) optimizes the QoS ⇒ complex QoS (C2)
  - ⇒ **Clustering** is **basis for** tackling the **other challenges**
  - ⇒ **Encodes domain knowledge**
    - ⇒ Used in planning & selection

Approach



Holistic Approach

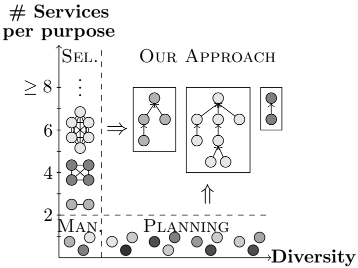
- **Issues** in:
  - **Planning**:
    - **C1** Scalability
    - **C2** QoS Aspects
  - **Selection**:
    - **C3** Flexibility
    - **C4** Functional Diversity
  - **Both**:
    - **C5** Reliability

- **Addressed** by:
  - Combining planning and selection, we address **C2** and **C3**
  - In the following, we focus on:
    - **C1** Scalability
    - **C4** Functional Diversity
    - **C5** Reliability

Assumptions

Assumptions

1. **Semantic annotations**
   - Interfaces **annotated**
   - Otherwise no **planning**
2. **Functionally related**
   - We know **which** services can be **combined**
   - Otherwise no **clustering**



3. **QoS known** at **any time**
   - QoS are **claimed by** the **provider**
     - ⇒ Violations → **penalty mechanisms**
     - ⇒ Alternative: (continuous) **monitoring** or **prediction** applied
   - **Input-independent QoS**: backup slides (page 106)
4. **Large number** of **services**
   - Otherwise **scalability not an issue**
   - **Possibilities** for optimization phase **limited**

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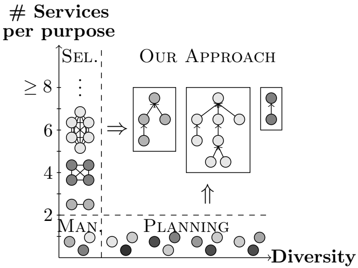

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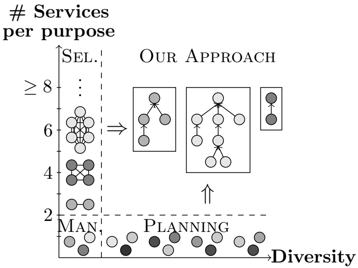

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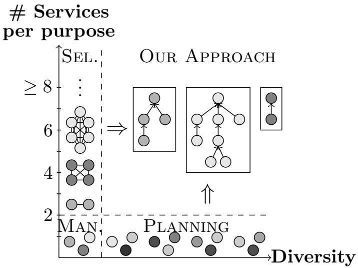

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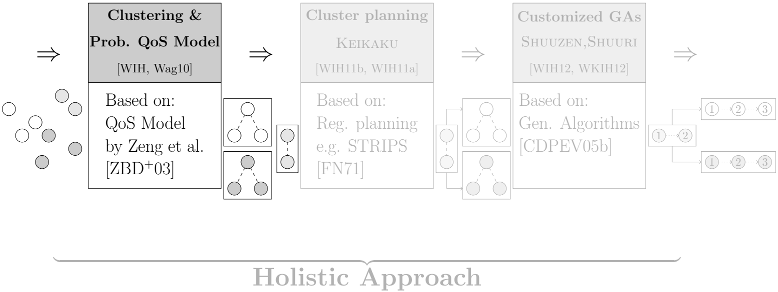
2. Service Clustering



Comparison with Related Work

- **Clustering** has been applied to **service discovery** [MPG+08]
  - **Different** service **comparison**, not applicable to composition
  - **No** additional **cached information** or **QoS model** based on the clustering
- In **service composition**, only **QoS-based** clustering algorithms
  - Not applicable to planning

Novelty

- Cluster Representatives
- SEO / Backup Services
- Caching of Service Parameters
- Probabilistic QoS Model

Based On

- Semantic Matchmaking
- QoS Model by [ZBD+03]

Service Clustering - Algorithm

- Services are **compared** with each other:
  - **Exact match**: same node

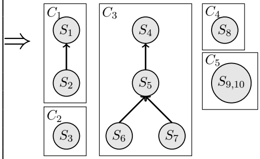
$$S \equiv S' \Leftrightarrow I \equiv I' \wedge O \equiv O' \wedge P \Leftrightarrow P \wedge E \Leftrightarrow E$$

  - **Plugin match**: edge between the nodes (weaker input and / or stronger output)

$$S \sqsubseteq S' \Leftrightarrow I \sqsupseteq I' \wedge O \sqsubseteq O' \wedge P' \Rightarrow P \wedge E \Rightarrow E'$$

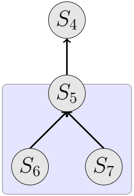
- Results in a **directed-acyclic graph**
- Connected components become the **clusters**
- **Root nodes** become **representatives**
- Takes around 6 sec. for 10,000 services

		Name	Inputs	Outputs
	S_1	BWImgToBarc.	BWImage	Barcode
Data-int.	S_2	ImageToBarcode	Image	Barcode
	S_3	GetProduct	Image	PID
	S_4	EUBarcodeDB	EANBC	PID
DB acc.	S_5	BarcodeToPInfo	Barcode	PID
	S_6	GetD9Info	Barcode	PID_{D9}
	S_7	Prod.Info.	Barcode	PID_{D14}
	S_8	GetReview	PID	Review
Dyn. data	S_9	GetCheapShop	GPS,PID	GPS, Price
	S_{10}	FindLocalShop	GPS,PID	GPS, Price



Service Clustering - Execution Orders

- **Observation**: **services** can be **replaced** with **services** from the **same node** and its **child nodes** (= subcluster):



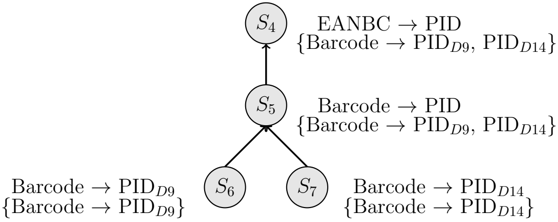
= Subcluster of S_5

- Introduce **service execution orders** (SEO)
  - Determines **which service** is executed
    - ⇒ Arrange services in fronts, then QoS aggregation
  - In case a service **crashes**, the **next service** in line is chosen, e.g. SEO for S_5:

  - Addresses challenge **C5**

Functional Parameter Caching

- Apart from backup services, the structure can be used as **background knowledge** in **planning** & **optimization**
- Helps to **avoid** unnecessary computations (challenge **C1**)



- Nodes **aggregate** parameter **types** of their **subcluster**
- **Super**types in **inputs** and **sub**types in **outputs** are omitted:

Inputs: $\{EANBC, Barcode\}$ $\quad EANBC \sqsubseteq Barcode \Rightarrow \quad \{Barcode\}$

Outputs: $\{PID, PID_{14}\}$ $\quad PID \sqsupseteq PID_{14} \Rightarrow \quad \{PID_{14}\}$

Service Clustering - QoS Model

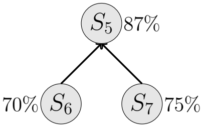
- **Consequences** of backup services: **probabilistic QoS**
- **Goal**: predict the values as closely as possible

  ⇒ Probabilistic QoS model:

  – Reliability of a node:

$$N^{rel} = 1 - \prod_{S \in cluster(N)} (1 - S^{rel})$$

Example:



$$N^{rel} = 1 - \Big(\underbrace{(1-0.87)}_{S_5 \text{ crashes}} \cdot \underbrace{(1-0.7)}_{S_6 \text{ crashes}} \cdot \underbrace{(1-0.75)}_{S_7 \text{ crashes}} \Big) \approx 99\%$$

- **Advantage**: build *reliable* systems with *low-cost* services

Service Clustering - QoS Model

- Introduce for each QoS attribute **three values**:
  1. **Best case**: first service executed successfully
  2. **Average case**:

$$\mathbb{E}[N^{price}] = \underbrace{S_1^{price}}_{\text{Price in case 1}} \cdot \underbrace{S_1^{rel}}_{\text{Probability of case 1}} + \\ + \underbrace{\left(S_1^{price} + S_2^{price}\right)}_{\text{Price in case 2}} \cdot \underbrace{\left((1 - S_1^{rel}) \cdot S_2^{rel}\right)}_{\text{Probability of case 2}} + \\ + \dots$$

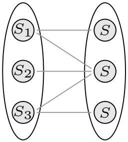
  3. **Worst case**: General idea: all services except for the last one fail [WKIH12]
     - ⇒ Too pessimistic in reality
     - ⇒ **Solution**: Apply Tchebysheff's inequality [WIH]

⇒ In the end, **7 objectives**:

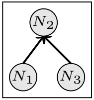
$$\left\{\left(p_{best}, \mathbb{E}[p], p_{worst}\right), \left(t_{best}, \mathbb{E}[t], t_{worst}\right), rel\right\}$$

Service Clustering - Extensions

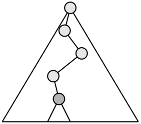
- Clustering **without type concepts** [WKIH12]:
  - No parameter annotations ⇒ clustering **still applicable**
  - Need relation *compatible*:



⇒



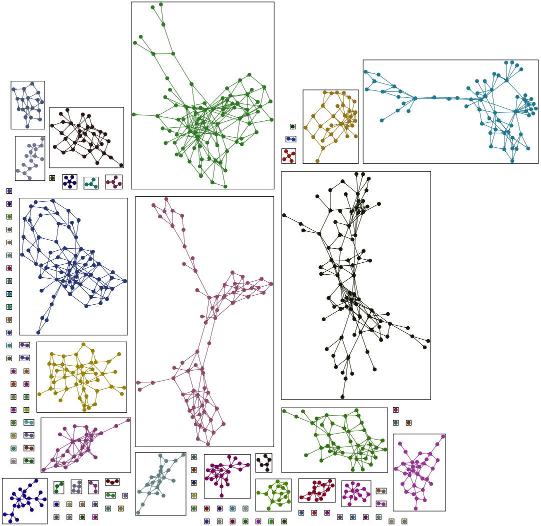
  - Applicable to scenarios with **given workflow template**
    ⇒ "Pure" service selection
- **Dynamic service environment**:
  - Efficient **insertion** of new services described in [MPG⁺08]
  - **Remove** service → **virtual** service
  - **Services or QoS change**: update all **parent nodes**:

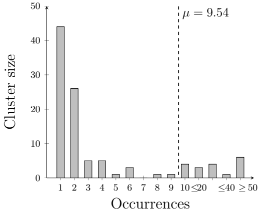


- **Virtual services** [WKIH12] . . . (backup slides)
- **Physical location** [WIH] . . . (backup slides)

Evaluation

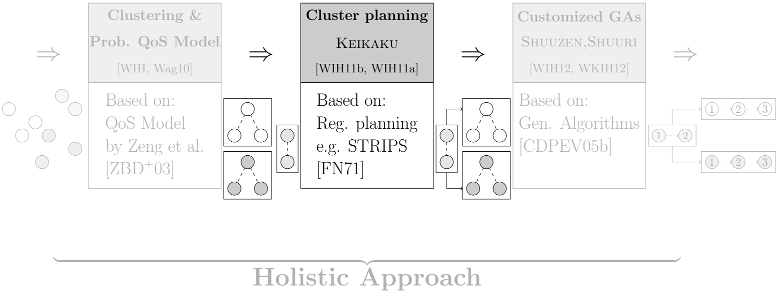
Clustering the OWLS-TC testset[2] (≈ 1,000 services):





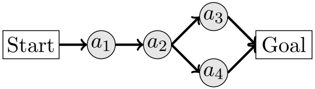
[2] http://www.semwebcentral.org/projects/owls-tc

3. Service Planning



Planning Algorithm

- **Planning**:
  - Given an **initial state** and **goal state**, plus a set of actions
  - Compose actions to establish a path between these states:



- **Service planning**:
  - Services and query are **translated into PDDL**, AI planner such as SHOP2 [WPS+03] or Xplan [KG06] are applied
  - Multiple QoS + constraints → no admissible heuristic
    - ⇒ **Scalability issues**: In each step, S possibilities → solution space is $\mathcal{O}(S^W)$, W unknown (**Challenge C1**)
    - ⇒ **Insufficient coverage** of QoS aspects (**Challenge C2**)

Novelty
- AI Planning on Cluster Level
- QoS-aware Template Gen.

Based On
- AI Regression Planning

Planning Algorithm - QoS Aspects

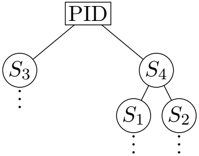
Challenge QoS Aspects (C2):

- **Multiple QoS** must be optimized and **constraints** must be met
- Domain-independent planner **mostly neglect QoS**
- Recently, **hybrid algorithms** have been proposed, such as QSynth [JZH+10]:
  - Won the WS-Challenge in 2009
  - Employs **simplified QoS model** and **ignores constraints**
    - ⇒ Used to evaluate our approach in [WIH11b] (next slides)

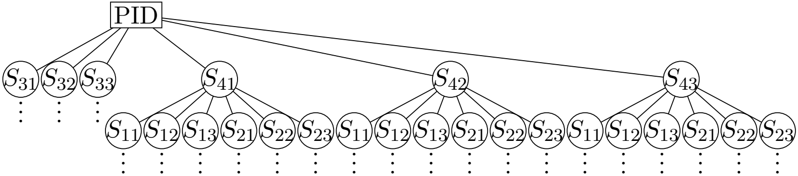
Planning Algorithm - Scalability

Challenge Scalability (C1):

- Many **functionally similar** but not equivalent services exist
  - ⇒ Search tree grows exponentially:



⇓ adding 2 alternatives per service ⇓

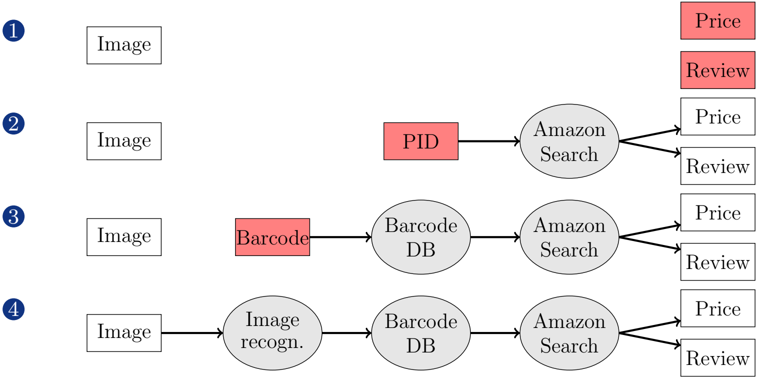


- **Not addressed** by related work in SOC community

Planning Algorithm - Scalability

Algorithm: Regression planning [GNT04] with services

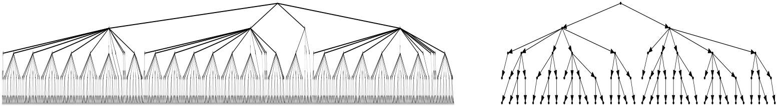
- Start with given goals
- Adding candidate services:



Problem when clusters are used instead of services:

1. When is a cluster **applicable**?
2. How does **adding** a cluster **modify** the set of **open goals**?

Planning Algorithm - Scalability



Service planning Cluster planning

- **Proposal**: **cluster planner** KEIKAKU:
  - Operates on **cluster level** instead of service level
  - Selects "promising" clusters
  - QoS are **optimized in the next stage**
    - ⇒ Multiple QoS and constraints can be considered
  - Consider **only representatives** in the clusters
  - **If** aggregated parameters in representatives **don't match**
    - ⇒ **Omit** entire cluster
    - ⇒ Avoids **unnecessary computations** with similar services ⇒ addresses scalability (Challenge **C1**)
  - **Else**:
    - ⇒ Determine **set of matching services** in the cluster (reverse lookup)
    - ⇒ **Weakest** input constitutes new goal

Example

Current plan:

GPS

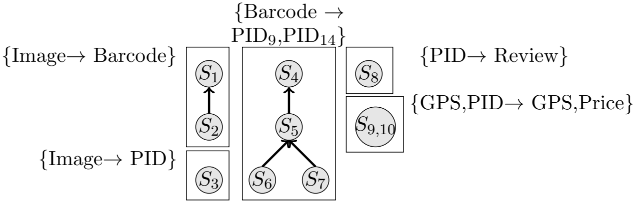
Image

GPS

Price

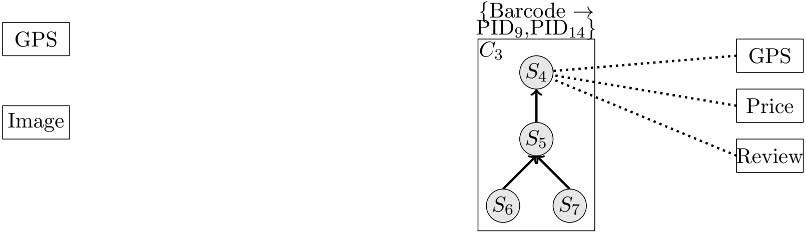
Review

Candidate clusters:

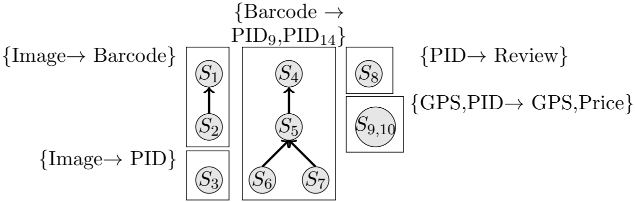


Example

Current plan:

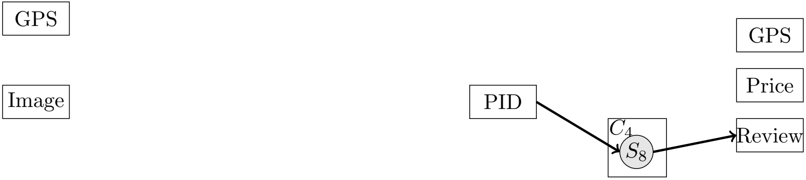


Candidate clusters:



Example

Current plan:



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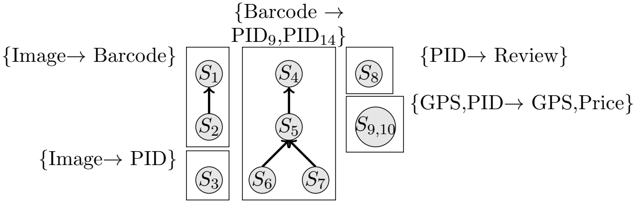

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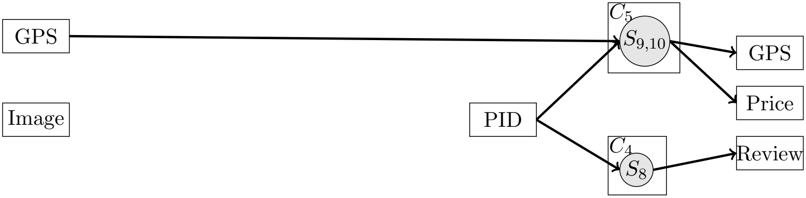
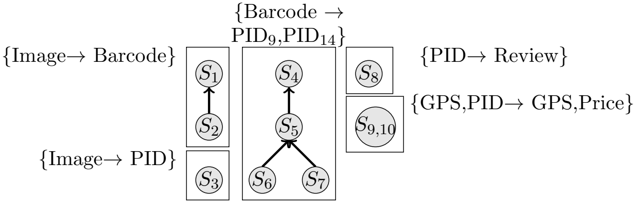
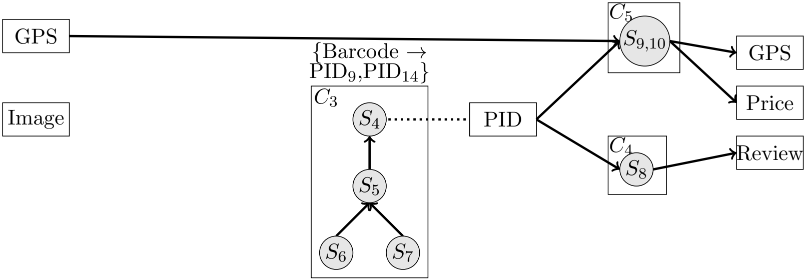


Candidate clusters:

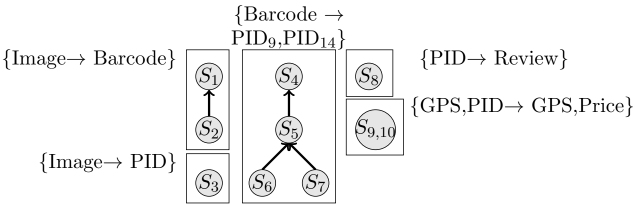


Example

Current plan:

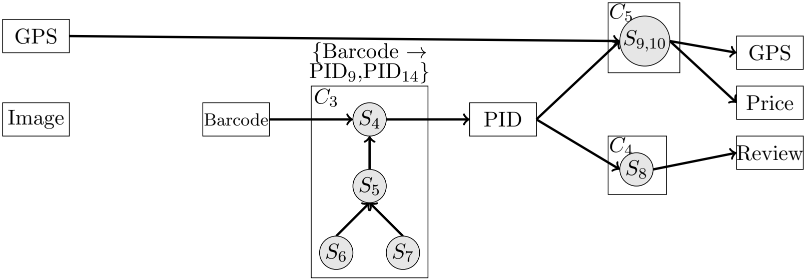


Candidate clusters:

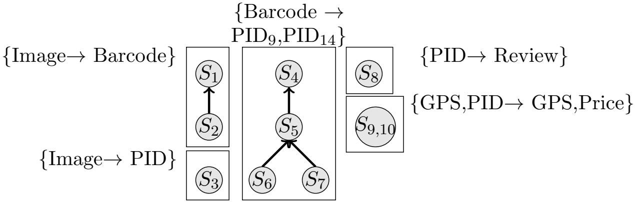


Example

Current plan:

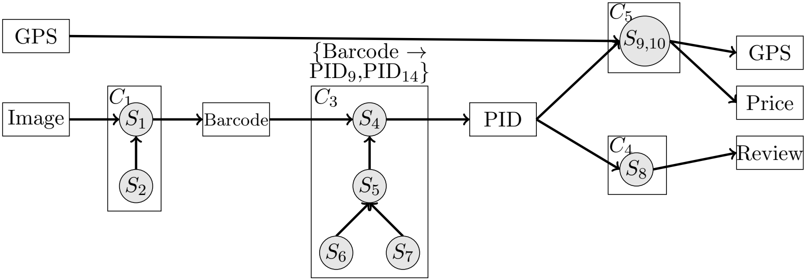


Candidate clusters:

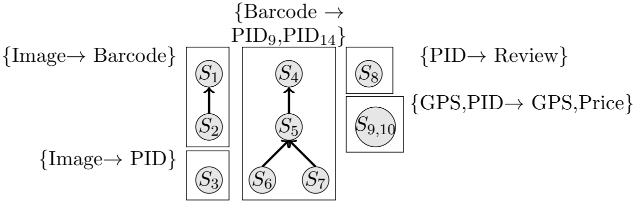


Example

Current plan:

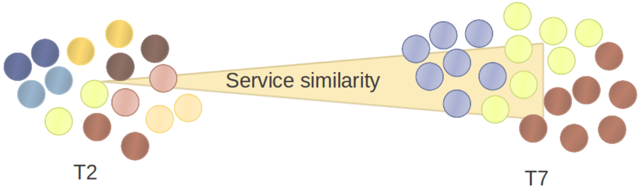


Candidate clusters:



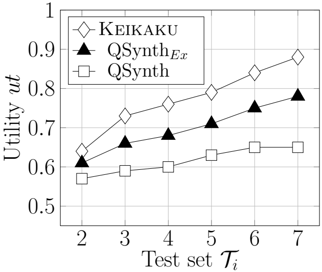
Evaluations - QoS Aspects (C2)

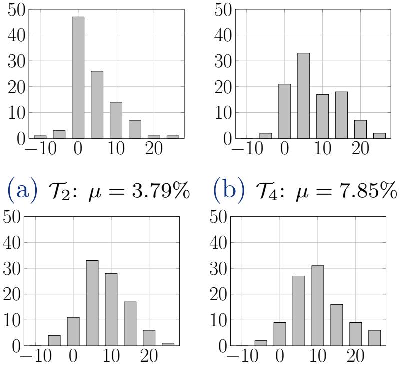
- Used **different test sets** called $T_2, T_3, \ldots, T_7$ containing 1,000 random services
- In every test set T_i for each service, i **similar services** are generated:



- Helps to examine **in which scenario** the KEIKAKU algorithm can be applied (narrow domain, open directory, . . .)
- Compared with **QSynth** [JZH+10], winner of the WS-Challenge 2009
- Added **extension of QSynth** that can handle backup services

Evaluations - QoS Aspects (C2)





(a) $\mathcal{T}_2$: $\mu = 3.79\%$ (b) $\mathcal{T}_4$: $\mu = 7.85\%$

(c) $\mathcal{T}_5$: $\mu = 8.60\%$ (d) $\mathcal{T}_7$: $\mu = 10.1\%$

Figure: ut(Keikaku) - ut(QSynth)

- Services are chosen based on a **simple heuristic**

⇒ **No** real **optimization** phase

- Clearly **outperforms** QSynth, especially when **many services per purpose exist (≥ 3)**

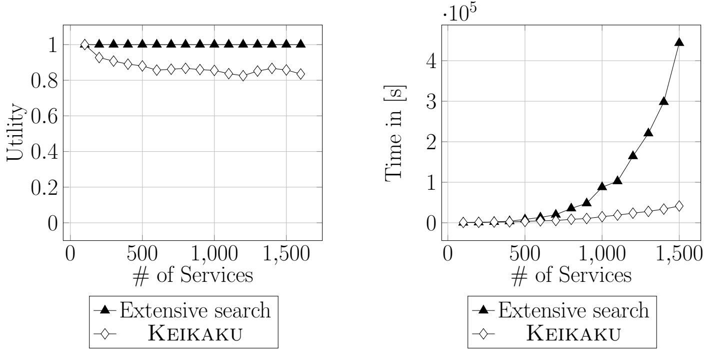
Evaluations - Scalability (C1)

- In the next evaluation, used the **test set generator** from the **WS-challenge**[3]
- Generated **100 services**
- Modified it to **generate test sets similar** to T_2 to T_7
- Compared with an **exhaustive search planner**
- Clusters were refined with a **simple hill-climbing algorithm**

⇒ Applying a GA might improve the results

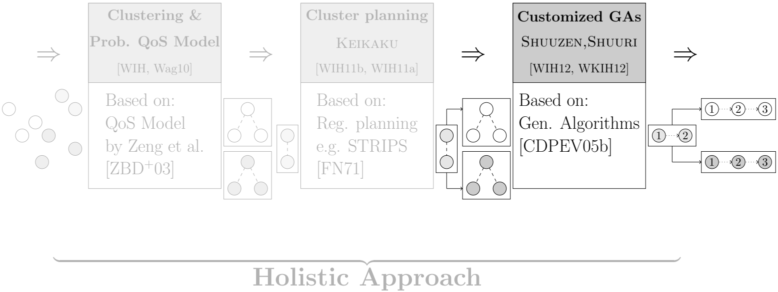
[3] http://ws-challenge.georgetown.edu/wsc10/

Evaluations - Scalability (C1)



- Utility is **near-optimal**
- **Runtime** of the extensive search is **exponential**
- Keikaku planner:
  leverages the similarity of the services

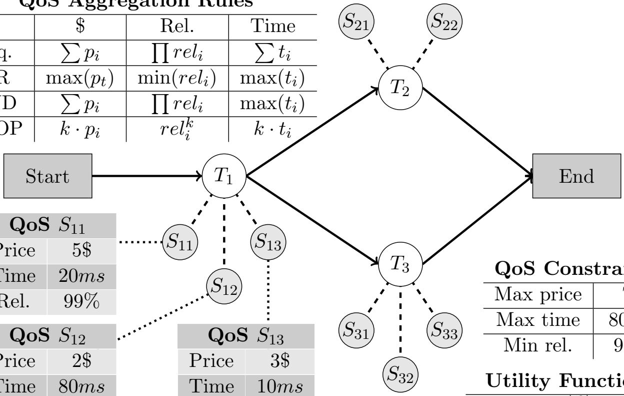
4. Workflow QoS Optimization



QoS-aware Service Selection [ZBD+03]

QoS Aggregation Rules

	\$	Rel.	Time
Seq.	$\sum p_i$	$\prod rel_i$	$\sum t_i$
OR	$\max(p_t)$	$\min(rel_i)$	$\max(t_i)$
AND	$\sum p_i$	$\prod rel_i$	$\max(t_i)$
LOOP	$k \cdot p_i$	rel_i^k	$k \cdot t_i$



QoS S_{11}	
Price	5\$
Time	$20ms$
Rel.	99%

QoS S_{12}	
Price	2\$
Time	$80ms$
Rel.	97%

QoS S_{13}	
Price	3\$
Time	$10ms$
Rel.	95%

QoS Constraints

Max price	7\$
Max time	$80ms$
Min rel.	90%

Utility Function

$$\mu(\mathcal{Q}) = \sum_{i=1}^{|\mathcal{Q}|} w_i \cdot \mathcal{Q}_i$$

- Goals:
  - **Utility** function is maximized
  - **All constraints** are met
- Very **active research field** in the past decade, mostly published on WWW, ICWS, ICSOC, and GECCO

Related Optimization Problems (more on backup slides!)

1. **Multiconstrained Optimal Path Problem**
   - **Problem**: exponential non-dominated paths possible
   - **Heuristics** only of **little help** [YZL07]
2. **Task Scheduling Problem**
   - **Problem**: most TSP algorithms apply **activity list representation**
   - **Only few** algorithms are **efficient**, still not competitive [JMG05]
3. **Multidimension multichoice 0-1 Knapsack Problem**
   - Applied by most related work, covers all aspects
   - **NP-hard** problem, search space: SPT^{WF}, scalability issues (**C1**) ⇒ **heuristics**
   - Both, MMKP and selection problem **tackled by**:
     - ⇒ Integer / Dynamic Programming [ZBD+03, HJHL09]
     - ⇒ Hill-climber [KIH11]
     - ⇒ **Genetic Algorithms** [CDPEV05b]
     - ⇒ MOO Meta-heuristics [WCSO08]
     - ⇒ ...

Open Research Problems

Open research problems:

1. **Flexibility (C3)**: Workflow **templates required**, **unusable** if requirements **change**
   - **Process template generator** described in [LGG+10]: instead of generating templates from scratch, this generator **retrieves templates** from **past execution logs**
   - We employ **planning**, **no** past execution **logs required**
2. **Functionally div. services (C4)**: Related approaches assume **large sets** of **equivalent services** exist [Str10]
   - Instead: **sparse solution space**
   - Uninformed meta-heuristics can get **stuck in local optima** (next slide)

   ⇒ Insufficient utility / performance

   ⇒ Addressed by **customized GA**
3. **Reliability (C5)**: Addressed by **ad-hoc replanning** [LZZ09], neglects **impact** on QoS
   - Alternative: select **multiple services** per task
   - **Increases** number of input **variables**

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Functionally Diverse Services (C4)

- **Related work** assumes services are **functionally equivalent**

  ⇒ Services **developed independently**

  ⇓

  Functionally **heterogeneous**

  ⇓

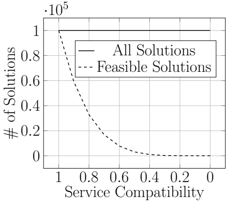
  Certain links **invalid**

- Consequences:
  - Local optima **more likely**, but still exponential search space
  - Meta-heuristics w/o domain knowledge **explore** search space **randomly**

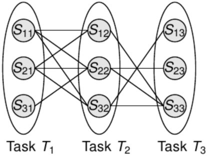
    ⇒ Slow convergence / low utility
  - Simple solution in [LM11]: just **modified** the **fitness function** (compared in eval.)
  - Solution space: $SPT^{WF} \Rightarrow SPT^{WF} \cdot p^{WF}$

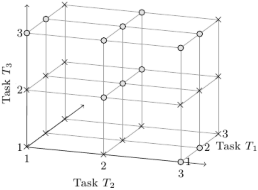
    Example: SPT = 10, WF = 50, p=0.5

$$10^{50} \Rightarrow 10^{50} \cdot 0.5^{50} \approx 10^{35}$$



SPT = 10, WF = 5





Including Functionally Diverse Services:

- **Tackled by:** Integrate **domain knowledge** (=service clustering) into existing meta-heuristic
  - **Customize** existing single-objective (SOO) and multi-objective optimization (MOO) **genetic algorithms** (GA)
    - ⇒ MOO-GA has **best performance** in the extended selection problem out of 15 algorithms
    - ⇒ **Easily customizable**
    - ⇒ Addresses Challenge **C4** (low utility in the context of functionally diverse services)
  - Propose **novel genome encoding** to cover SEOs
    - ⇒ Addresses Challenge **C5** (low reliability)

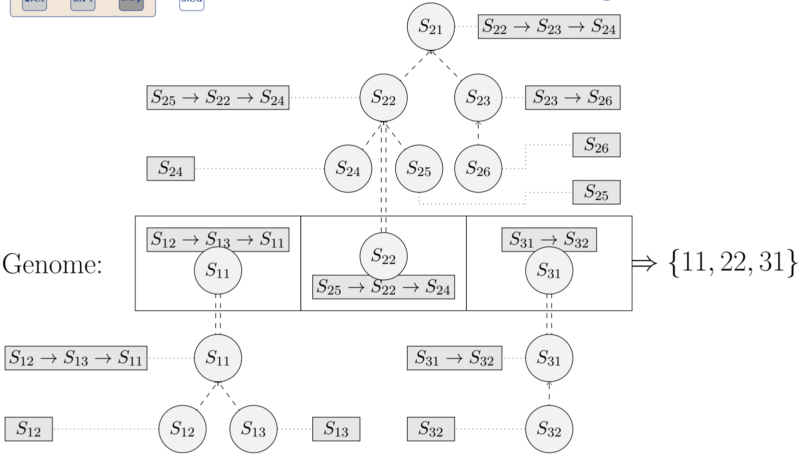
Novelty

- Genome Encoding of SEOs
- Customized GA Operators

Based On

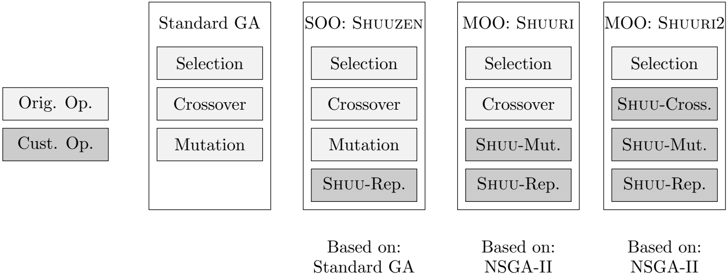
- GA and their application to service selection

Encoding of a Genome



- **Each cell** encodes a **SEO**, cached in the cluster nodes.
  - ⇒ **One decision** variable for up to 3 services
  - ⇒ No increase in the number of input variables
  - ⇒ Preserves utility / performance, fault-tolerant workflow possible

Customized GA operators

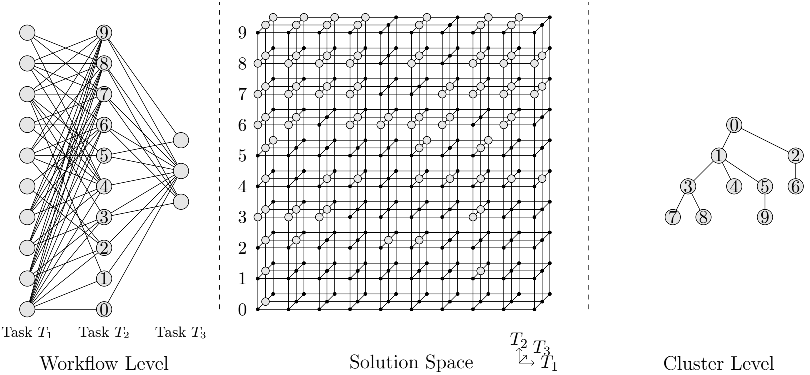


- **Customized operators** leverage service clustering:
  - SHUU-Repair: Find **functionally valid** solution (**C4**)

    infeasible solution → feasible solution
  - SHUU-Mutate: Explore **feasible** solution space (**C4**)

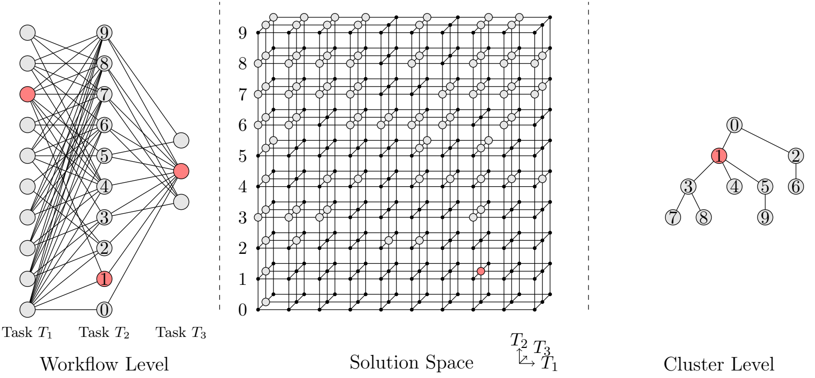
    feasible solution → feasible solution
  - SHUU-Crossover: Max. **distrib.** of backup services (**C5**)
- **Remark**: This presentation covers SHUURI/SHUURI2

Optimization Phase



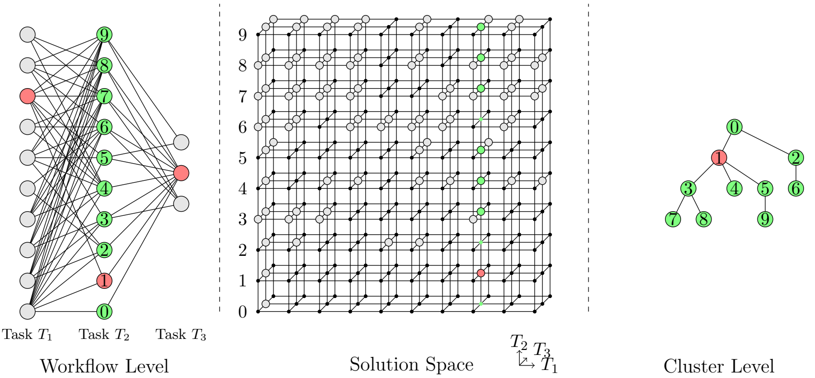
- **Left**: For each task, select one service
- **Middle**: Visualizes the search space, one point = path
- **Right**: Clustering of task T_2, new view

Custom ops. - 1. Mutate operator



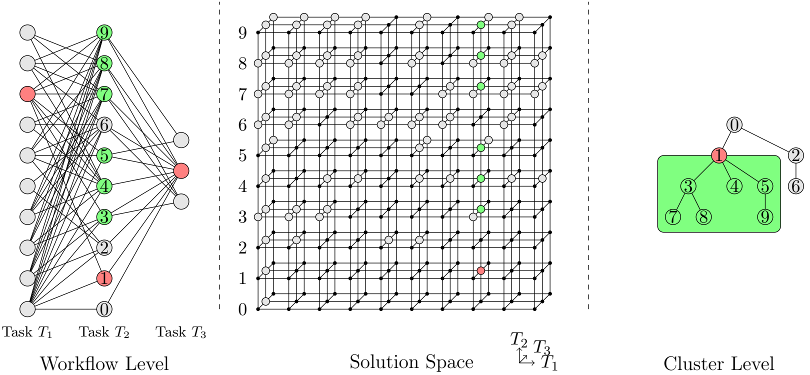
- Given solution: $\{7, \mathbf{1}, 1\}$
- In each generation, **mutate operator** is applied
  - ⇒ Explore **new solutions**

Custom ops. - 1. Mutate operator



- **Uninformed** mutate operator picks task T_2
- Selects random service from T_2
  - 3 of 9 possibilities (33%) **invalid!**
  - Given $p = 50\%, WF = 3$, $1 - 0.5^3 \approx 97\%$ offspring invalid

Custom ops. - 1. Mutate operator

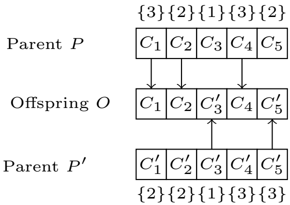


- Shuu-Mutate: given a feasible solution
  - ⇒ With probability P_{mut} **only** pick **nodes** from **subcluster**
  - ⇒ Explores **feasible solution subspace** efficiently

Custom ops. - 2. Crossover operator

- SHUU-Crossover: Modified **uniform crossover** operator
- Genomes are **annotated** with number of **independent service locations**
- Compare the annotations of both **parent cells**:
  - If one parent **has more**: 75% pick this node
  - Else, pick one with 50%

⇒ Favors cluster **nodes** with **distributed services**



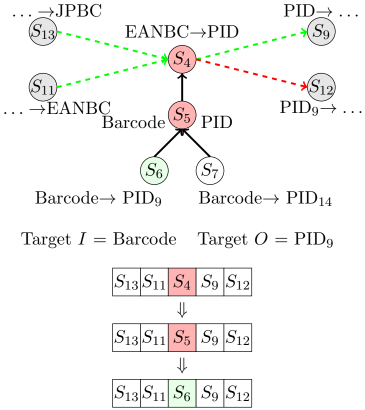
Custom ops. - 3. Repair operator

- SHUU-Repair: Applied with **probability** P_{rep}
  - Leverage **domain knowledge**
  - By exp.: 33% best trade-off
- Compute **target** inputs and outputs by:

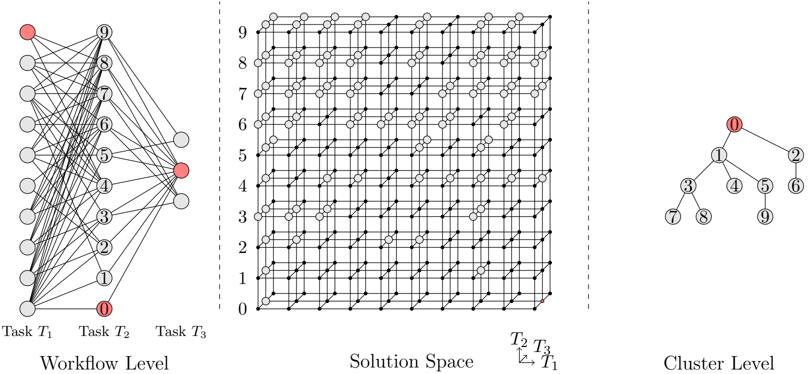
$$\text{Target } I : C \in \mathcal{O} \ . \ \forall I \ . \ I \sqsubseteq C$$

$$\text{Target } O : C \in \mathcal{O} \ . \ \forall O \ . \ C \sqsubseteq O$$

- Intuition: **Invalid** solutions "**pushed**" to feasible solutions, uses **cached parameters**
- Applicable for **SOO** and **MOO**
- **No similarities** with repair extensions of GAs [CB98]

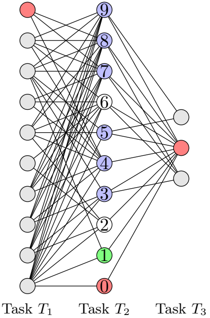


Custom ops. - 3. Repair operator

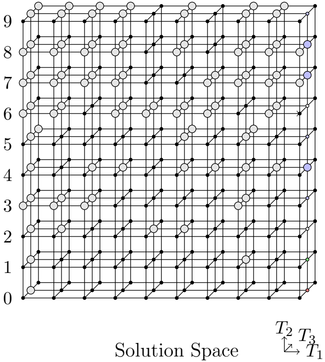


⇒ Start: Invalid solution $\{9, \mathbf{0}, 1\}$ selected

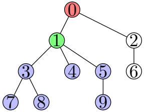
Custom ops. - 3. Repair operator



Workflow Level



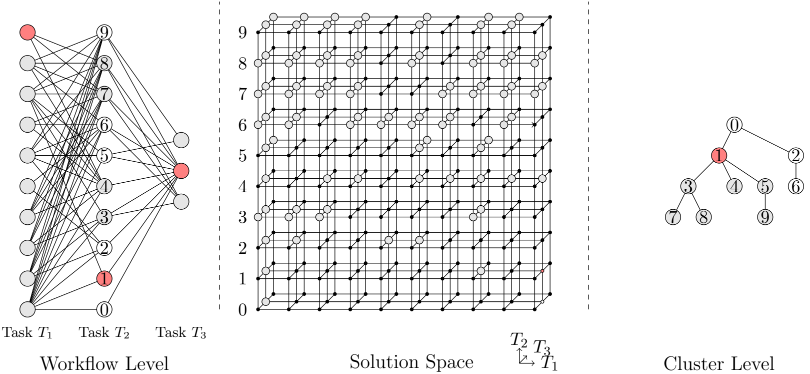
Solution Space



Cluster Level

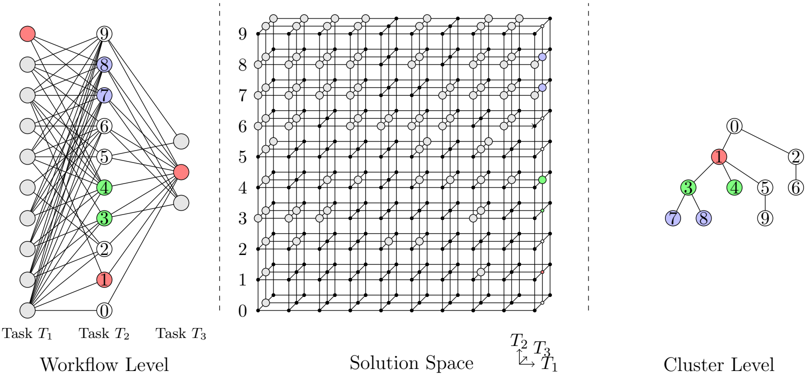
⇒ Subcluster **2** pruned ⇒ clustering = search tree

Custom ops. - 3. Repair operator



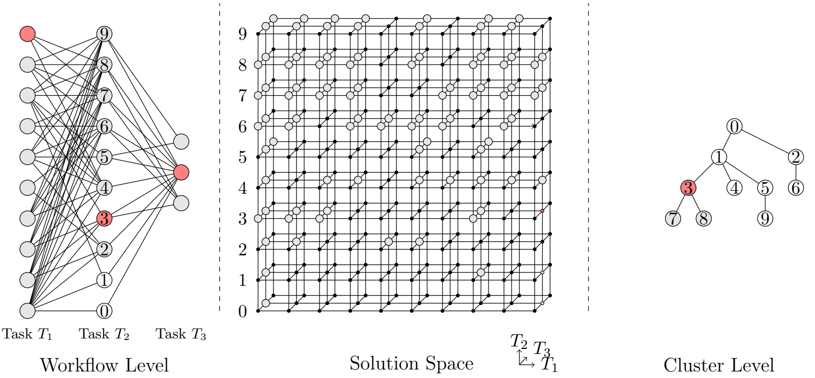
⇒ Descend to **1**, still invalid

Custom ops. - 3. Repair operator



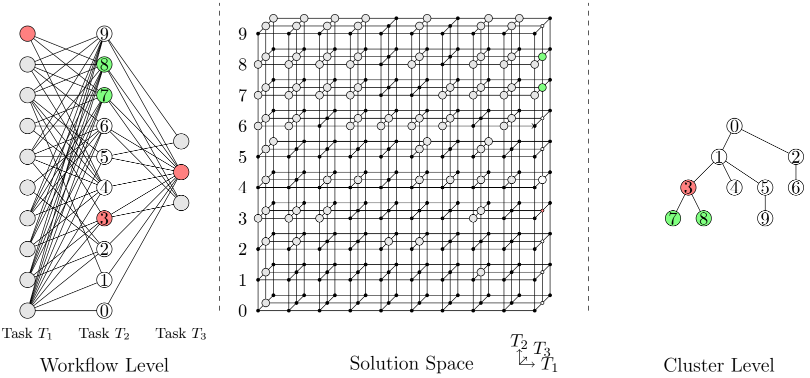
⇒ According to clustering, only **3** and **4** are valid

Custom ops. - 3. Repair operator



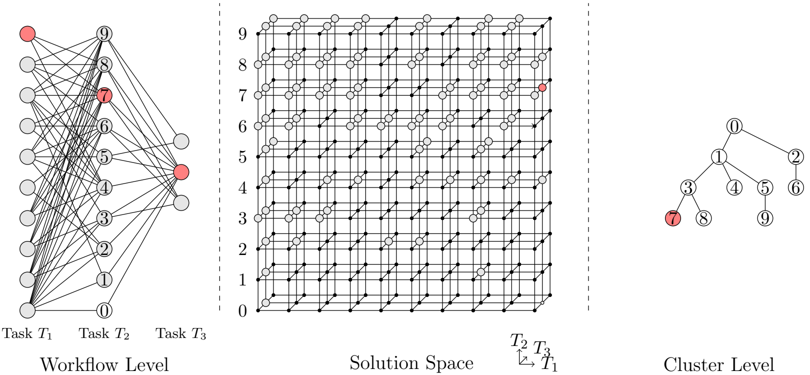
⇒ Randomly select **3**

Custom ops. - 3. Repair operator



⇒ Both **7** and **8** are valid

Custom ops. - 3. Repair operator



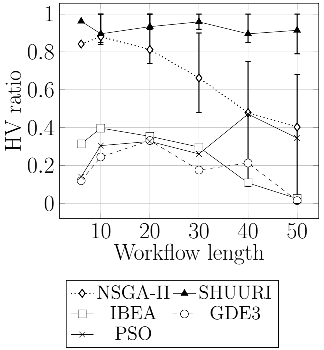
⇒ Repaired genome by replacing **0** with **7**

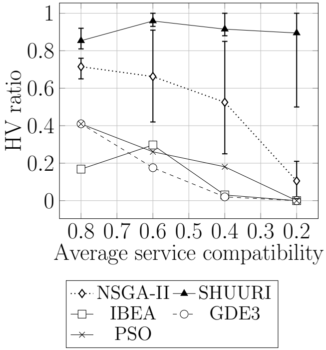
Evaluations - MOO - Settings

- Used the **JMetal** framework[4]
- **Extended** the **NSGA-II** algorithm ⇒ **SHUURI**
- **Compared** it with **15 MOO** algorithms (top-5 in the next slides)
- Generated 20 services for each task, associated with types from the SUMO ontology[5]
- **QoS randomly** generated, except for the price
  - In [WIH] we've used the **QWS dataset**[6] (backup slides)
  - Service **reliability from real data**
  - Moreover, implemented a **workflow simulator**
- Each test case was evaluated 100 times, max. runtime 5000msec

[4] http://jmetal.sourceforge.net/
[5] http://www.ontologyportal.org/
[6] http://www.uoguelph.ca/~qmahmoud/qws/index.html

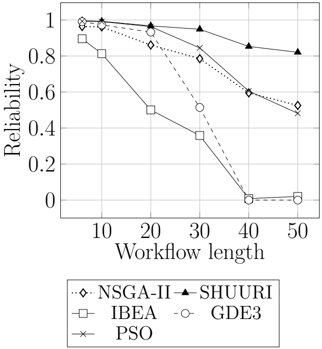
Evaluations - MOO (C4) - Results

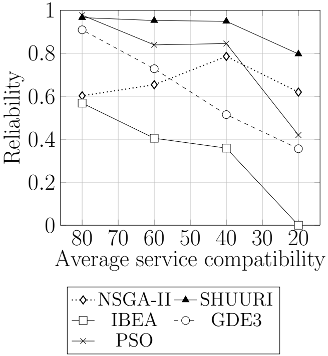




- Bounds show 90% of evaluation results
- Hypervolume (HV) ratio computed by **merging the fronts** of all algorithms
- With **increasing problem size** (workflow length, low compatibility) SHUURI **outperforms** other algorithms

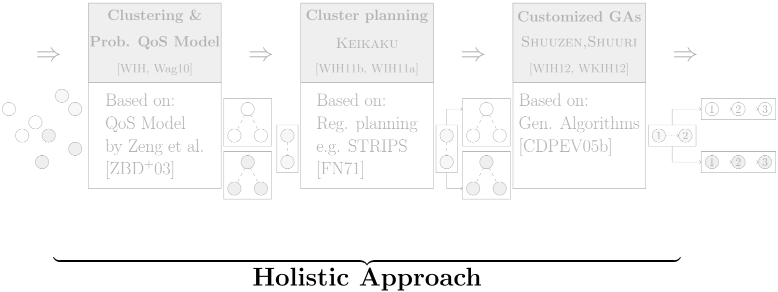
Evaluations - MOO (C5) - Results





- **Same setting** as before, comparing the **reliability**
- **Backup slides**: using workflow simulator and simulated hosts ⇒ physical location

Holistic Approach



Start movie of the prototype

5. Summary

Central Contributions 1/2 (repeat)

Issues in existing approaches:

Planning

C1 **Scalability**

- ⇒ Many **similar services**
- ⇒ **Branching factor** in search tree very **large** ⇒ exponential search space

C2 **Complex QoS Aspects**

- ⇒ Optimize **multiple QoS**, meet hard QoS **constraints**
- ⇒ No admissible heuristic, NP-hard

Selection

C3 **Flexibility**

- ⇒ User requirements **might change**
- ⇒ **Re-computation** of workflow might be **necessary**

C4 **Functional Diversity**

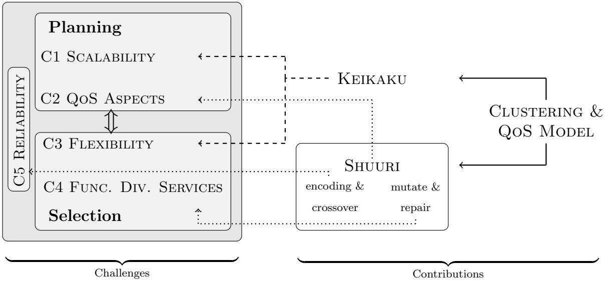
- ⇒ **Sparse** solution space → domain-independent heuristics **get stuck** in local optima
- ⇒ Low utility / slow convergence

Both

C5 **Reliability**

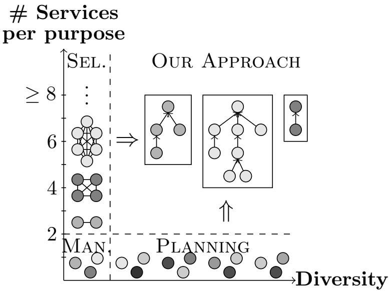
- ⇒ Selecting additional **backup services** for each task **increases number** of input **variables**
- ⇒ **Impact** of service crashes **on QoS unclear**

Central Contributions 2/2 (repeat)



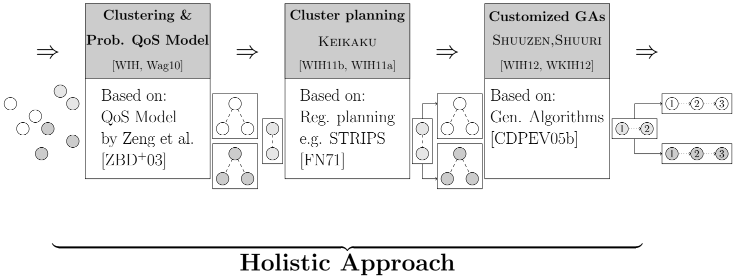
- **Extended QoS model and Clustering**
  - ⇒ Basis for Keikaku and Shuuri, encodes domain knowledge
  - ⇒ Estimates **QoS** of service **crashes**
- **Scalable cluster planer**: Keikaku
  - ⇒ **Avoids unnecessary comparisons** of services efficiently
  - ⇒ Computes workflow templates with "promising" QoS
- **Customized GA**: Shuuri
  - ⇒ **Encoding** and **crossover** : efficiently encodes **multiple services** with only **one variable**, maximizes **distribution** of backup services
  - ⇒ **Mutate** and **repair** : fast exploration of feasible solution space, **higher utility**, **faster convergence**

Assumptions (repeat)



- **Requirements**:
  1. **Semantic** annotations → Keikaku
  2. **Func.** related services → clustering, Keikaku, Shuuri
  3. **QoS** → Shuuri
  4. **Large number** of services → Shuuri
- **Evaluation results**: better results with ...
  - ... **growing** number of **services** per purpose
  - ... **increasing** degree of **diversity**

Applicability to other domains



- Functional **clustering** leverages background **knowledge** on the **service functionalities**
- **Characteristics**: functionally related entities, arranged in **hierarchy**
- Related fields:
  - Software components: theoretically applicable; however, usually only one entity per functionality

  ⇒ **Modified planning problem**

  ⇒ **Extended service selection problem** (based on MMKP)

Thank you very much for your kind attention!

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