A Systematic Literature Review of Requirements Modeling and Analysis for Self-adaptive Systems

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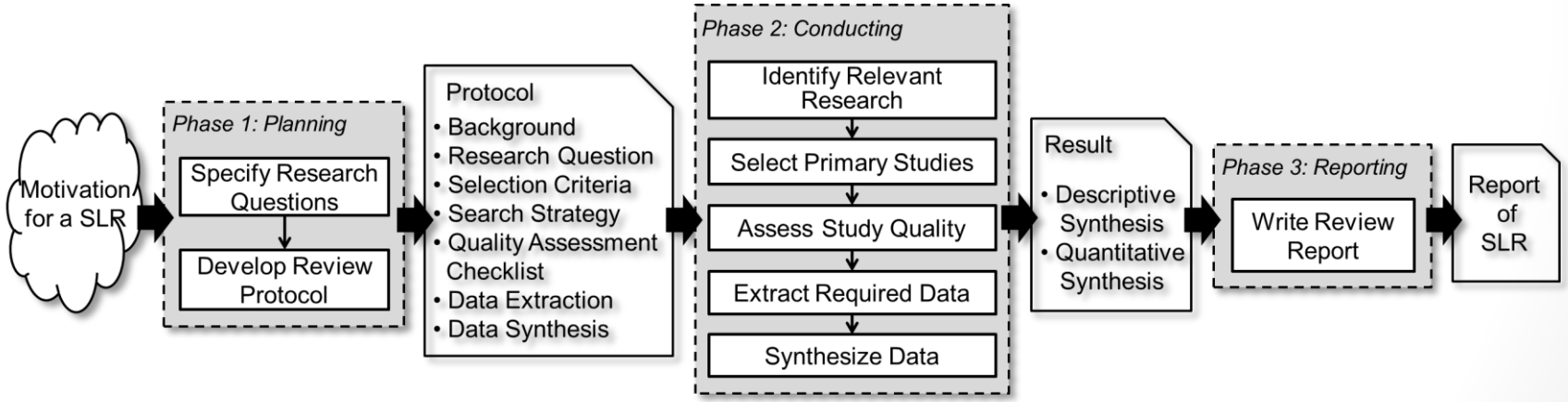
Introduction and Motivation

- Self-adaptive systems (SASs)
  - Adjust their behaviors in response to the dynamic changes
  - Characterized by self-* properties (self-reconfiguring, self-healing, self-protecting and self-optimizing)
- Requirements engineering (RE) for SASs defines
  - Both domain logic and adaptation logic
  - What/why/where/when/who/How to adapt
- The objective of this paper is to
  - Systematically investigate the research literature of requirements modeling and analysis for SASs
  - Summarize the state-of-the-art research trends
  - Categorize the used modeling methods and relevant RE activities
  - Classify the quality attributes and application domains
  - Assess the quality of current studies
  - Generate the most active research topics

Research Method

- Systematic Literature Review (SLR) a systematic methodology of
  - Defining answerable research questions
  - Searching the literature for the best available evidence
  - Appraising the quality of the evidence
  - Collecting and aggregating available data
- Research Process



- Protocol
  - Define basic review procedures
  - https://www.dropbox.com/s/t6i4ock5g11zo2x/SASProtocol.pdf

Research Questions

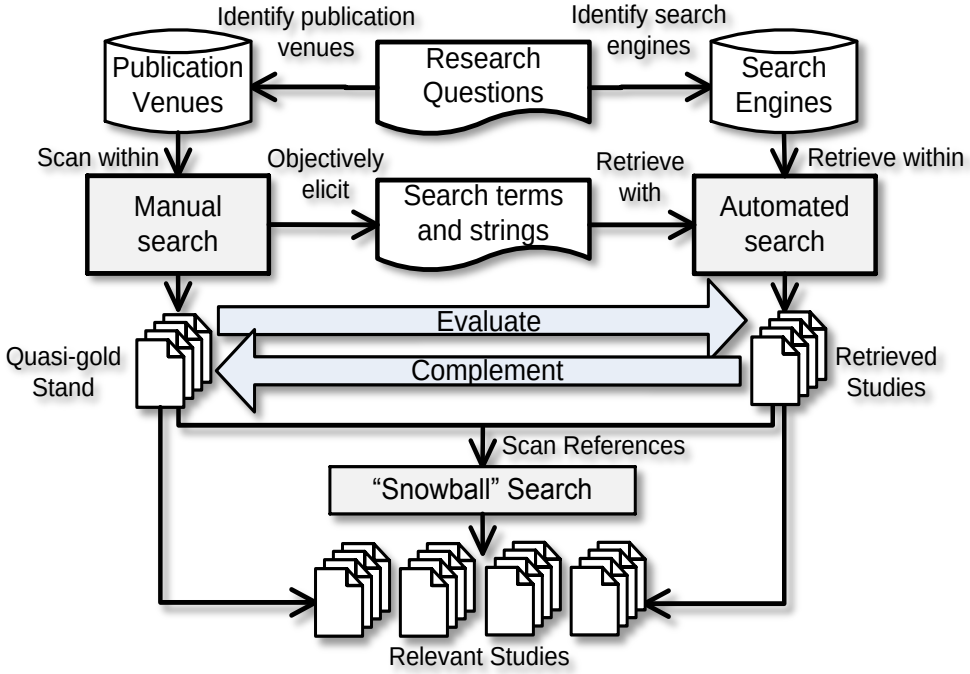
- We define seven research questions (RQ):

Research question	Type
RQ1: What is the time/venue/research group/region distribution of the publications?	Publication
RQ2: What modeling methods and RE activities are studied? RQ3: What requirements quality attributes and application domains are involved?	Content
RQ4: Which methods are better applied and have more rigorous evaluation? RQ5: Which RE activities are presented and discussed more detailedly?	Quality
RQ6: What topics can we generalize based on the content of selected studies? RQ7: What is the relationship between topics and modeling methods?	Topic

- The questions can be categorized into four types:
  - Publication type: questions related to publication information
  - Content type: questions answered by extracting textual data
  - Quality type: questions answered by assessing the quality of papers
  - Topic type: questions related to the topics of relevant studies

Search Process

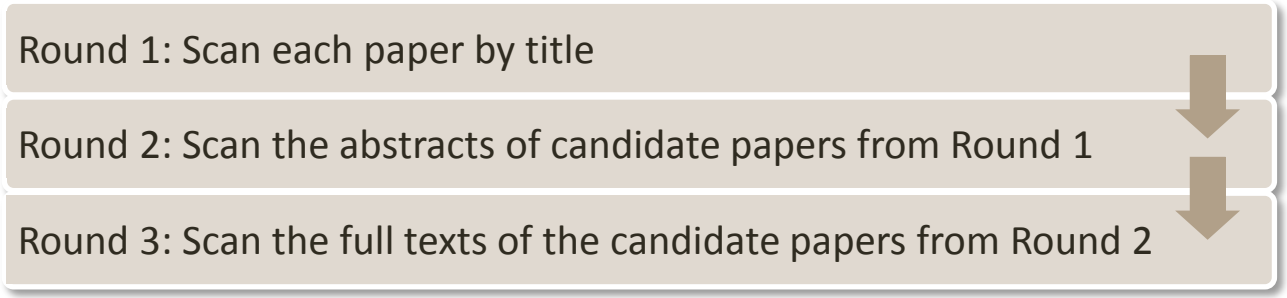
- *Search process* aims to identify relevant studies based on search strategies. It is underpinned by



- Quasi-gold standard (QGS)
  - A set of known studies established by manual search
  - Used to define search strings
  - Used to evaluate the performance of search strings

Selection Procedure and Criteria

- Selection procedure consists of three rounds:



- Relevant studies are selected with inclusion criteria and exclusion criteria defined below.

Inclusion criteria	Exclusion criteria
C1: Published time between 2003.1-2013.9	C5: In the form of books
C2: Focus on requirement modeling and analysis for self-adaptive systems.	C6: In the form of editorial, abstract, keynote, poster or a short paper (less than 6 pages)
C3: Related to concrete RE activity	C7: Opinion pieces or Position papers
C4: Involve concrete modeling methods and evaluation to the methods	C8: Focus on summarizes the existing research work, e.g. roadmap or survey

- Retrieved papers are firstly checked with exclusion criteria and then checked with inclusion criteria.

Search engines

- Search engines are
  - Databases for the automated search
  - Digital libraries where publication venues are provided
- We choose 6 search engines that cover the RE literature
  - ACM Digital Library, IEEE Xplore, Springer

  Science Direct, EI Compendex, Web of Knowledge
- The qualified 11 conferences/symposiums and 10 journals/books are mainly chosen according to the Australian ERA Outlet Ranking.

Conference/ Symposium	ERA ranking	Journal/ Book	ERA ranking
ICSE	A	TSE	A
FSE	A	ASEJ	A
RE	A	JSS	A
ASE	A	ToSEM	A
REFSQ	B	ESE	A
MODELS	B	IST	B
ICAC	B	SoSyM	B
CAiSE	B	REJ	B
SEAMS	N/A	TAAS	B
SASO	N/A	SESAS	N/A
RE@runtime	N/A		

Search Strings

- By using text mining, we define the search strings:

Item	Search string
S1	(“self-adaptive systems” OR “dynamically adaptive systems” OR “adaptive system” OR “Adaptive software” OR “self-adaptive software” OR “adaptive service” OR “web systems” OR “socio-technical system” OR “self-adjusting systems” OR “autonomic computing” OR “self-adapting software”)
S2	“model requirements” OR “modeling requirements” OR “Requirements modeling”
S3	“specify requirements” OR ”specifying requirements” OR “requirements specifying” OR “requirements specification”
S4	“monitor requirements” OR “monitoring requirements” OR “requirements monitoring”
S5	“aware requirements” OR “requirements-aware” OR “requirements awareness” OR “requirements-awareness”
S6	“diagnose requirements” OR “diagnosing requirements” OR “requirements diagnosing” OR “requirements diagnosis”
S7	“detect requirements” OR “detecting requirements” OR “requirements detection”
S8	“verify requirements” OR “verifying requirements” OR “requirements verifying” OR “requirements verification”
S9	“requirements” AND (“self-adaptation” OR “self-reconfiguration” OR “self-repair” OR “self-healing” OR “self-tuning” OR adaptation OR configuration OR reconfiguration OR “decision making” OR “decision-making” OR “adaptation behavior” OR “behavior”)
S10	“evolution requirements” OR “requirements evolution”

Quality Assessment Checklist

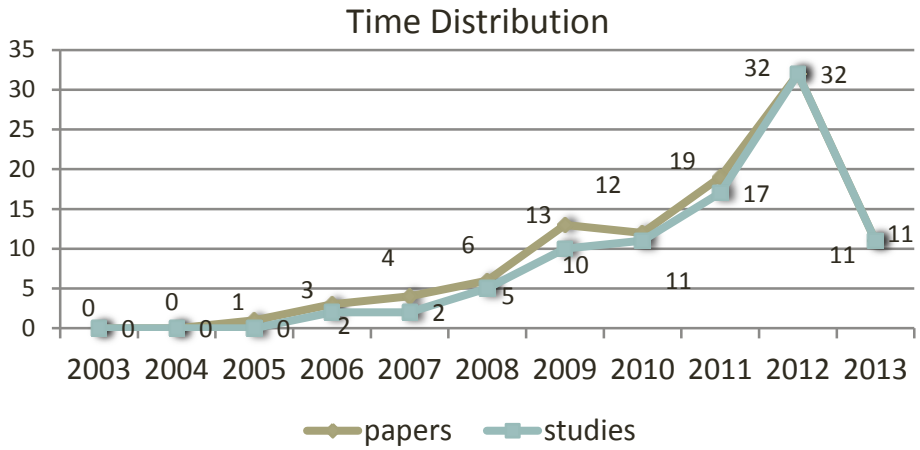
- Quality Assessment checklist is designed to evaluate whether a modeling method or a RE activity is maturely or rigorously conveyed in the literature.

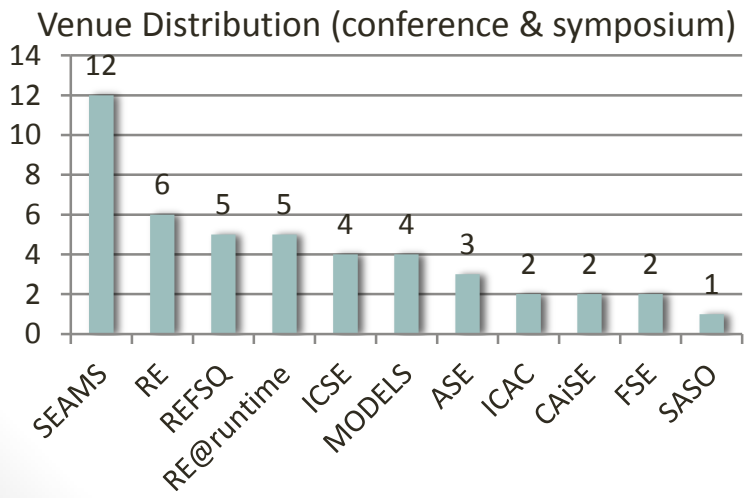
Assessment question	Optional answer and score
A1: How clearly is the problem of study described?	Explicitly=1/Vaguely=0.5/No description=0
A2: How clearly is the research context stated?	With references =1/Generally=0.67/ Vaguely=0.33/No statement=0
A3: How detailedly is the modeling method conveyed?	Step by step=1/Relatively detail=0.67/ Generally=0.33/Vaguely conveyed=0
A4: How detailedly is the RE activity elaborated?	Explicitly=1/General steps=0.67/ Vaguely=0.33/Disorderly=0
A5: How rigorously is the method evaluated?	Simulation=1/Detailed case study=0.67/ General case study=0.33/No evaluation=0
A6: How explicitly are the contributions presented?	Explicitly=1/Generally=0.5/No presentation=0
A7: How explicitly are the limitations discussed?	Explicitly=1/Generally=0.5/No discussion=0
A8: How explicitly are the insights and issues for future work stated?	With recommendations=1/Generally=0.5/ No statement=0

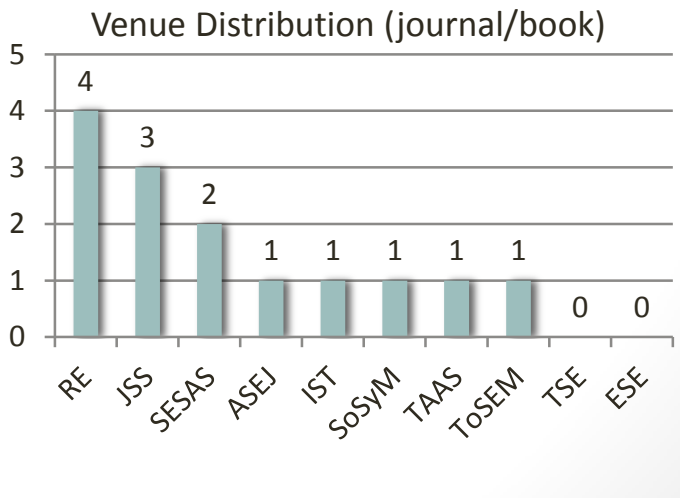
Results and Discussion

***RQ1.1**: What are the time and venue distribution of the publications?*

- We select a total of 101 relevant papers with 11 repeated studies, in which 46 conference/symposium papers and 14 journal/book papers are covered in the publication venues.



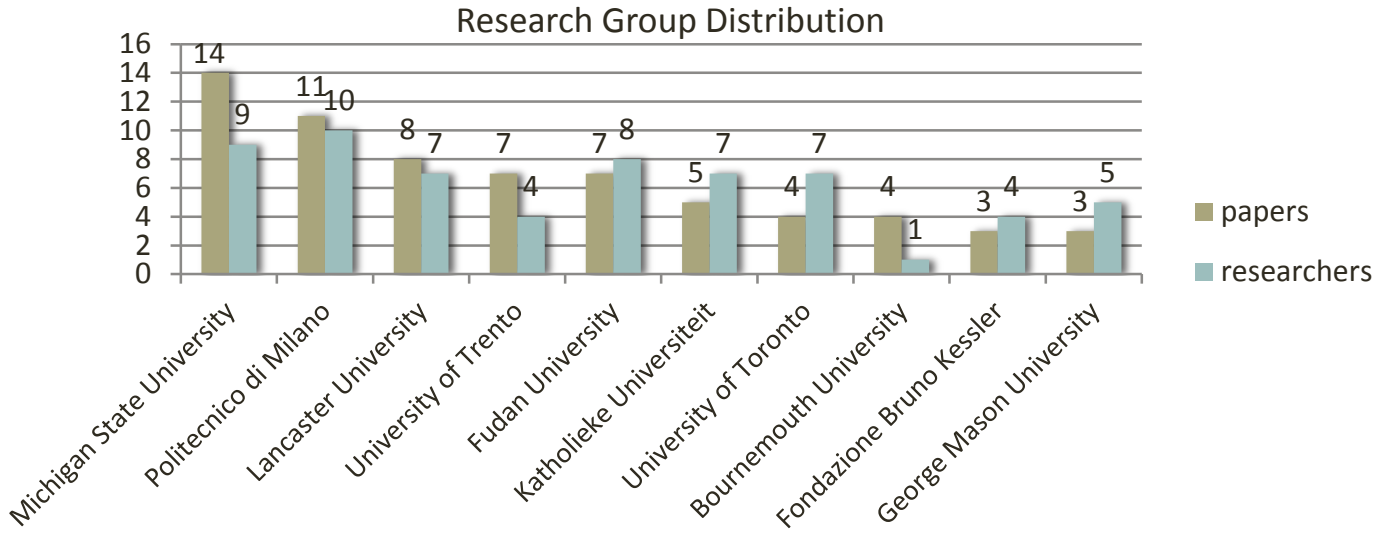


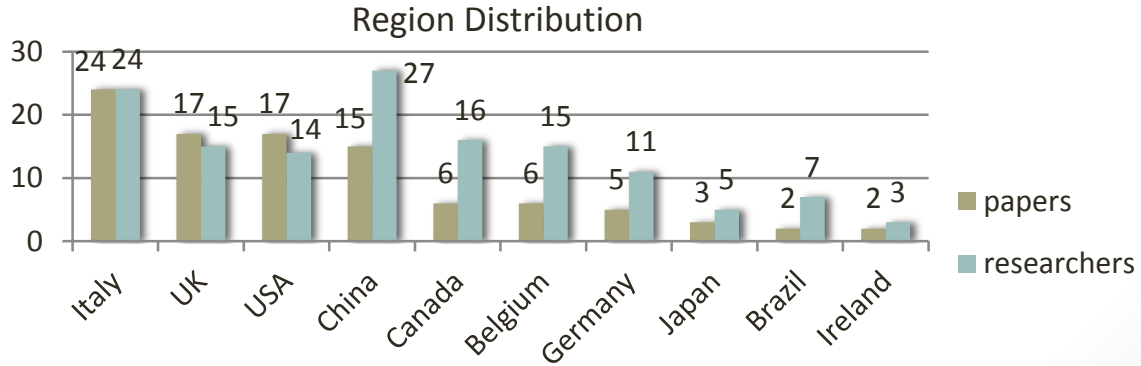


Results and Discussion

***RQ1.2**: What are the research group and region distribution of the publications?*

- The selected papers are from 29 research groups in 13 regions (according to the first author) and the 137 researchers are from 43 groups in 17 regions.
- Most of these papers are from European countries (58/101), followed by American countries (25/101) and Asian countries (18/101).

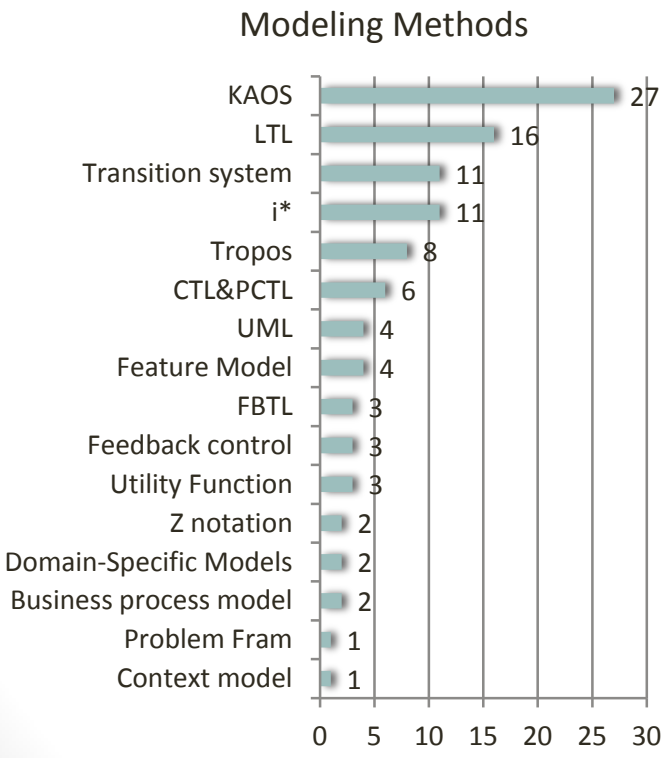


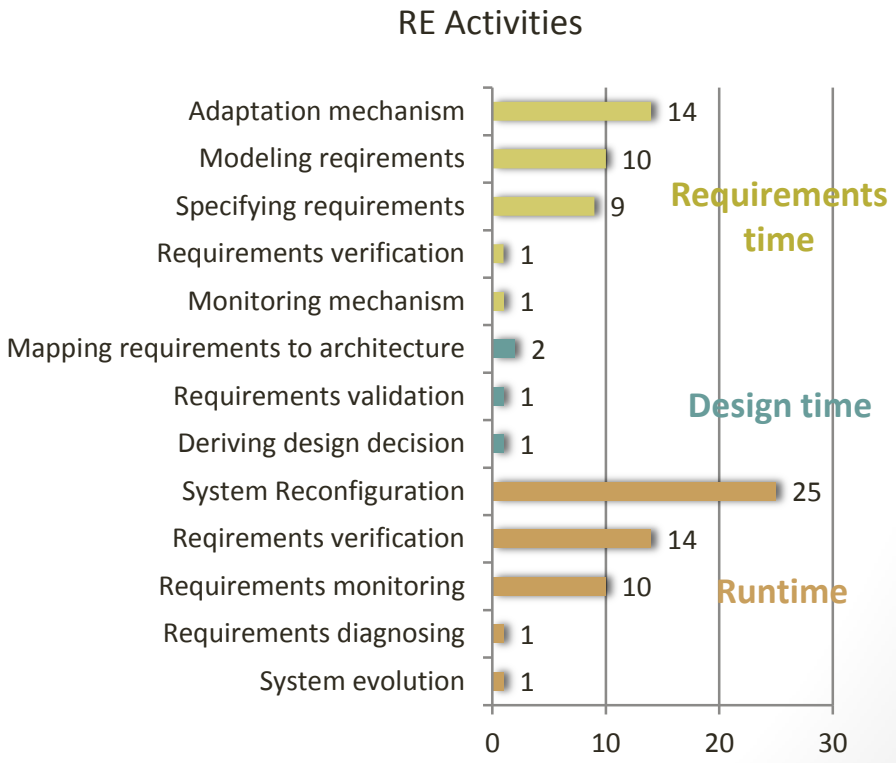


Results and Discussion

RQ2: What modeling methods and RE activities are studied?

- Modeling methods are categorized according to the objective of modeling activities, including requirements, context and system.
- RE activities are classified according to the period in the lifecycle, including activities at requirements time, at design time and at runtime.

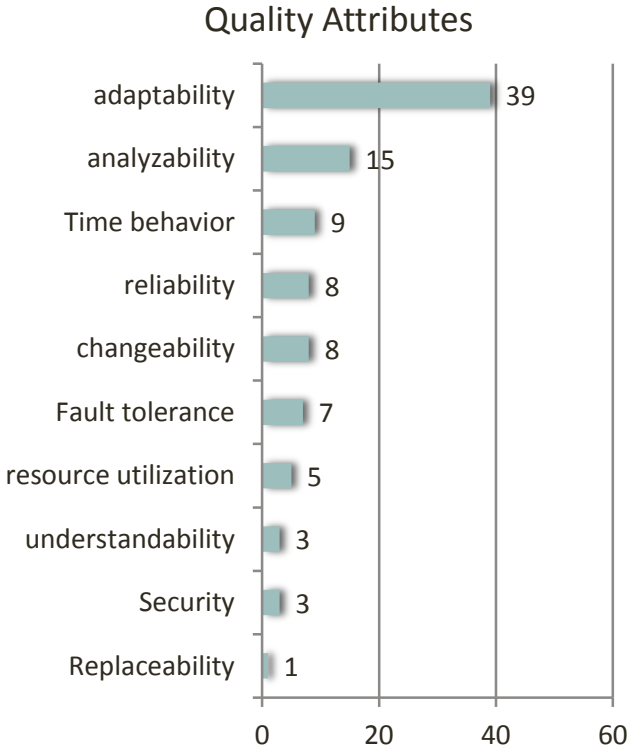


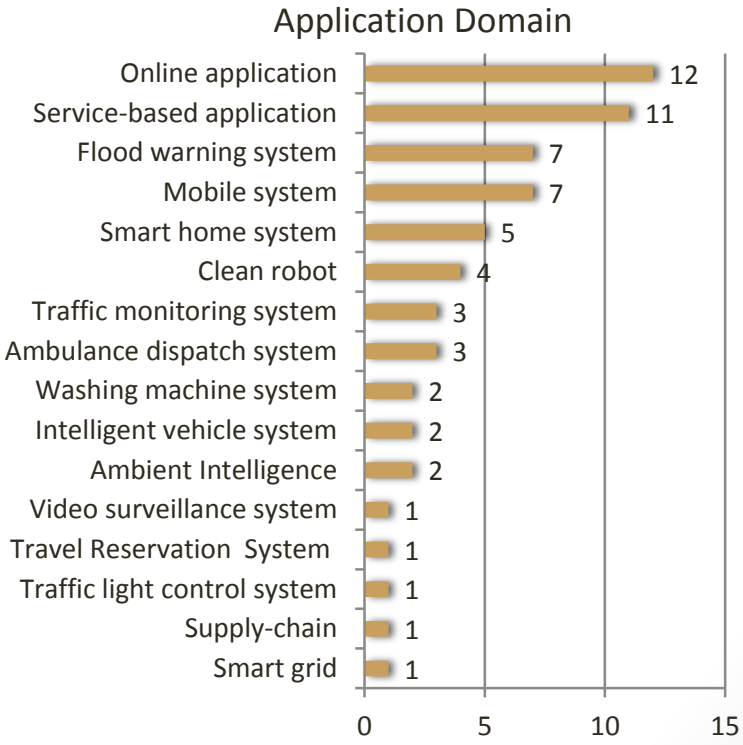


Results and Discussion

***RQ3**: What requirements quality attributes and application domains are involved?*

- We investigate the requirements quality attributes (Figure 9) related to SASs according to ISO 9126.
- The application domains can benefit researchers and practitioners to choose appropriate demonstrations and design reasonable experiments.

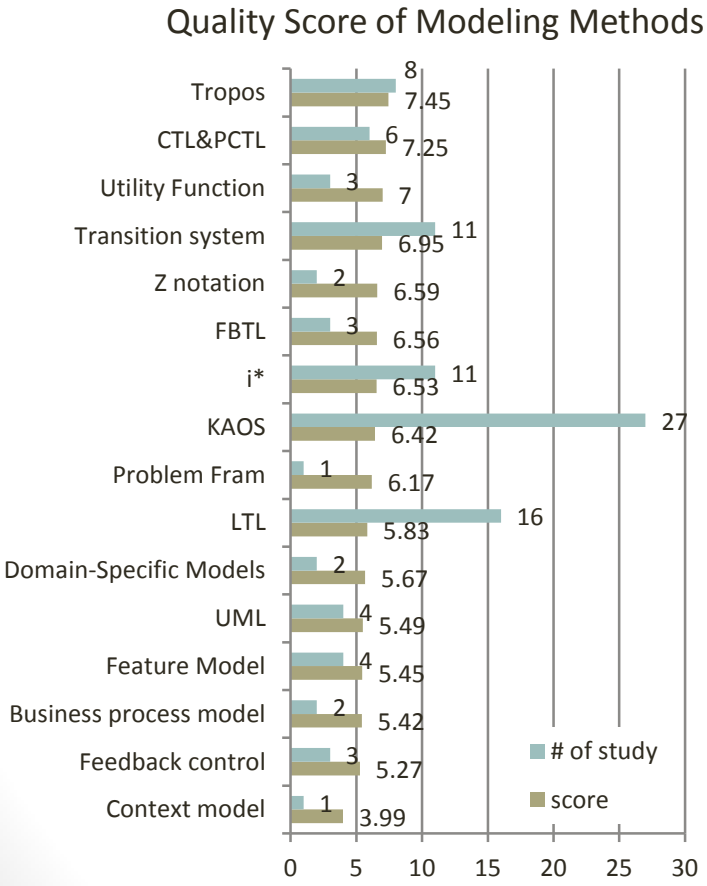


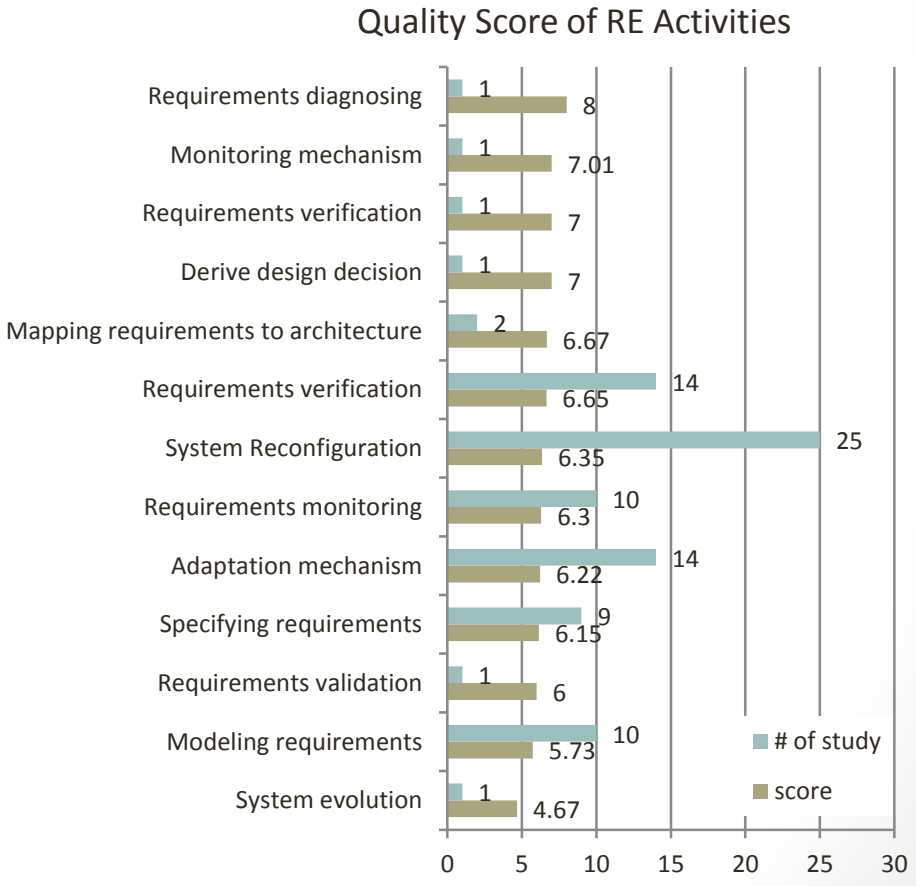


Results and Discussion

***RQ4**: Which methods are better applied and more rigorously evaluated?*
***RQ5**: Which RE activities are presented and discussed more detailedly?*

- Relevant studies are appraised according to the quality assessment checklist





Results and Discussion

***RQ6**: What topics can we generalize based on the content of selected studies?*

***RQ7**: What is the relationship between topics and modeling methods?*

- We code segments of relevant studies with 135 key phrases and 44 of them are kept after removing duplicate phrases.
- These codes are categorized into 7 topics according to the content of papers.

Topic	Sub-topic	KAOS	i*	Tropos	Feature Model	Context model	Problem Frame	UML	Business process model	Domain-Specific Model	Transition system	LTL	CTL&PCTL	FBTL	Z notation	Utility Function	Feedback control
Modeling requirements, contexts and systems	context modeling and analysis	1		1		1											
	defining SAS development framework			2													
	describing adaptation in feedback loop										1						1
	modeling adaptation mechanism	5	2	1			1	1	1								
	model adaptation with security requirements	2															
	modeling and reasoning on NFR										1						
	modeling domain requirements for SAS									1							
	modeling requirements evolution	1															
	modeling RE activities of SAS		1														
	modeling security requirements	1															
	modeling systems behavior											1					
	modeling variant of self-adaptive systems									1							
	cope with requirements changes		2														
	customize software with preferences	1															
Specifying adaptive elements	specifying and managing self-* properties														1		
	specifying adaptation mechanism										1						
	specifying adaptation semantics	3										2					
	specifying adaptive programs											2					
	specifying adaptive requirements	1															
	specifying self-adaptive systems							1				1			1		

1

2

Results and Discussion

***RQ6**: What topics can we generalize based on the content of selected studies?*

***RQ7**: What is the relationship between topics and modeling methods?*

Topic	Sub-topic	KAOS	i*	Tropos	Feature Model	Context model	Problem Frame	UML	Business process model	Domain-Specific Model	Transition system	LTL	CTL&PCTL	FBTL	Z notation	Utility Function	Feedback control
Dealing with uncertainty	addressing environmental uncertainty	1						1									
	decision making with uncertainty		1								2					1	
	mitigating uncertainty through adaptation	1	1											1			
	modeling sources of uncertainty		1														
	modeling uncertainty in requirements													1			
Verification and validation	QoS verification						3				1		1				
	requirements modeling and validation											1					
	validating the qualities of system										1	1					
	validating requirements at design time													1			
	verifying NFR at runtime										1		1				
	verifying adaptive programs											3					
	verifying requirements at runtime										3	1	3				
Monitoring and detecting	monitoring requirements	2		1								1				1	1
	detecting inconsistency within contextual req.			1													
	detecting requirements violation	1										1				1	
Adaptation and decision making	self-tuning with unanticipated changes				1												
	dealing with runtime variability reconfiguration				1												
	requirements-driven runtime reconfiguration	5	2	1	2						4						1
	runtime evolution by dynamic reconfiguration	1											1				
	runtime reconfiguration with model evolution								1								
	decision making to protect security req.	1															
	optimizing design decision			1													
	trade-off between FR and NFR							1									
mapping	mapping requirements model to arch. model		1									2					

Challenges (1/2)

- Modeling method
  - Integrate context model with other models within the scenario of system adaptation
  - Apply problem Frame to modeling adaptation mechanisms
  - Utilize other control types, such as adaptive control, feedforward-feedback control, fuzzy control, etc.
- RE activity
  - Requirements-driven architecture adaptation
  - Requirements-driven evolution
  - Runtime diagnosing
- Application domains
  - Application interact with other software, systems or the human.
  - E.g. Mobile computing, Smart Grid, Cyber Physical Systems, Internetware
- Quality attributes
  - Security and self-protection
  - Replaceability and self-recofiguration
  - Understandability and self-explanation

Challenges (2/2)

- Improving research quality
  - Quantitative models and mathematical models
  - Integrate other disciplines with RE for SASs :
    - **Control theory** to design adaptation mechanisms in SASs
    - **Fuzzy set theory**, **probabilistic theory** and **probability theory** to describing uncertainties of both requirements and context
    - **Optimization theory, decision theory and game theory** to derive appropriate adaptation decisions
- Research hot topics
  - Modeling adaptation mechanism
  - Specifying adaptation semantics
  - Mitigating uncertainty through adaptation
  - Verifying requirements at runtime
  - Monitoring requirements
  - Requirements-driven reconfiguration at runtime

Threats to Validity

- Potential Bias (researcher's bias)
  - Adopt Kappa coefficient to assess the selection results
  - Joint meeting and discussing with external researchers
- Internal Threats (systematic errors)
  - Establish a rigorous protocol in advance
  - The protocol is reviewed by external reviewers
  - Final results are derived by integrating the result of different participants
- External Threats (omission, new published studies)
  - Taking into account all the primary venues in this area
  - Integrating manual search, automated search and "snowball" search together

Conclusion

- Increased trend in paper publication
  - 22 primary publication venues
  - Top 3 conference/symposium: SEAMS, RE, REFSQ
  - Top 3 journal/book: RE, JSS, SESAS
  - 101 papers from 29 research groups in 13 regions
  - 137 researchers from 43 groups in 17 regions
- 16 modeling methods used in 11 RE activities
- 10 quality attributes are studied
- 16 application domain are involved
- Large gaps in research quality
- 7 topics and 44 sub-topics
- Research gaps and challenges

Thank You

Q&A