# SAGE DevOps, Gameful Intelligent Tutoring, and Publication

Final Report

COMS6901 – Projects in Computer Science, Fall 2018

Alex Dziena / ad3363

Lily Yu Li / yl4019

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# Introduction

Over the course of this semester we've extended the DevOps work done in previous semesters, prepared a preliminary draft of a reference architecture for a computational thinking-focused educational platform based on SAGE's current implementation, and integrated the existing Gameful Intelligent Hinting codebase with the rest of SAGE.

Specifically, we implemented code-style checking and documentation[1], protection of mainline code branches through gated pull requests[2], performed a clean merge of Summer 2018 and Spring 2018's conflicting Parson's Puzzles work, and added code coverage[3] checking of all primary SAGE codebases. We developed a reference, conceptual, and concrete architecture for SAGE, and validated the reference architecture against code.org's implementation[4]. We have created an API, frontend interface, and bridge to our inference and analyses codebases to integrate Gameful Intelligent Hinting work done in this and past semesters with the SAGE UI.

We addressed the following Epics and Features:

| Epic | Feature |
|---|---|
| SAGE Integration | DevOps MVP |
| | Workstream Integration |
| Gameful Intelligent Tutoring | Intelligent Hinting 1.1 |
| Survey, Field Study Design, and Publication Strategy | SAGE Feasibility Study & Publication |

# Related Work

DevOps work on SAGE to date has been primarily focused on automation and improving the time-to-productivity for new researchers. With the introduction of continuous integration and deployment, and configuration management for shared and local development environments, the focus of DevOps work this semester shifted to improving code quality and overall project health, and avoiding regressions.

There is also an opportunity this semester to focus on the publication of a reference architecture for a computational thinking-focused educational platform, following the submission of SAGE's feasibility study to SIGCSE last semester. This reference architecture has been discussed in previous semesters, but a draft has not yet been created[1, p. 8].

## SAGE Integration: DevOps

**[Dimensions of DevOps]**

Lwakatare, et al. performed a survey of DevOps practices and identified four primary dimensions of DevOps practice: collaboration, automation, measurement, and monitoring. The paper goes on to specify a conceptual framework for characterizing DevOps practices[3].

This paper, in particular the sections on collaboration and automation, helped guide the prioritization and implementation of DevOps work items this semester including:

1. Pull requests and code reviews
2. Integration of the Parson's Puzzle Spring 2018 and Summer 2018 work

**[Role of collective ownership and coding standards in coordinating expertise in software project teams]**

This paper explores expertise coordination as an important emergent process through which software project teams manage software development challenges, in particular within the framework of Extreme Programming (XP). Maruping et al examine the relationship between collective ownership and coding standards with software project technical quality in a field study of 56 software project teams comprising 509 software developers, and found that collective ownership and coding standards play a role in improving software project technical quality. They find that coding standards strengthens the relationship, resulting in higher technical quality[5].

This work inspired the SAGE coding standards as documented in the SAGE wiki[1] and guided our implementation of automated linting and code-standards checking within our continuous integration framework.

**[Parameterizing random test data according to equivalence classes]**
Professor Kaiser, et al. present a framework for parameterized random test case generation for machine learning applications. As stated in this paper, there is no reliable test oracle for ML applications; i.e. we can not, with reasonable confidence, predict the correct output for a given random input[6].

This research guided the implementation of a “fuzz” testing data generation framework, that generates inputs to the behavior detection engine in SAGE’s Gameful Intelligent Tutoring codebase, which will be used after end-of-semester code commits to generate a set of ML test cases.

**[Gitflow]**
Per Phillips’ survey on branching and merging practices[7], Git was used by the second highest number of survey participants (narrowly less respondents than were using Subversion), and some of the primary determinants of success, or satisfaction with, a branching strategy were 1) minimizing merge conflicts, 2) increasing the frequency of upstream merges, and 3) using Experiment, Feature, and Release branches. GitFlow[8] is a branching and merging workflow, using Git, that minimizes merge conflicts, enables Continuous Integration systems to perform frequent upstream merges, and accommodates experiment, feature, and release branches.

SAGE’s pull-request based branching and merging policy is an implementation of GitFlow. It has the added advantage of automated and enforced code review and build validation for all commits.

## Gameful Intelligent Tutoring

**[Hints: Is It Better to Give or Wait to Be Asked?]**
Razzaq, et al. found that students learned more reliably when they were provided with a mechanism to receive hints-on-demand rather than being provided with hints proactively in a “just-in-time” hinting system[9]. Because this effect was more pronounced in students who asked for a larger number of hints, the study may suggest that the relative benefit of hints-on-demand vs proactive hints increases as a student needs increasing amounts of assistance.

This paper provided us the inspiration and rationale for a natural language interface to an on-demand hinting system.

**[Autonomously Generating Hints by Inferring Problem Solving Policies]**

Piech, et al. performed analysis on a large amount of student solutions data gathered from Code.org and proposed several different path modeling algorithms used to learn a Problem Solving Policy (PSP), a policy that returns a suggested next partial solution for all partial solutions to a given puzzle, i.e. a PSP $\pi$ is defined as $s' = \pi(s)$ for all $s \in S$, with $S$ being the set of all possible solutions. The algorithms used to learn this PSP were compared, with a class of algorithms called Desirable Path algorithms (Possion Path and Independent Probable Path) performing the best - producing PSPs closest to the paths contained in an expert-labeled set of suggested paths[10].

“Poisson Path”-based PSP learning and hint generation were implemented last semester[11]. This semester, we integrated the hint generation engine with SAGE’s UI.

**[Delivering Hints in a Dialogue-Based Intelligent Tutoring System]**
Zhou, et al present an implementation of CIRCSIM-Tutor, a dialogue-based intelligent tutoring system. The system used a a labeled corpus of dialogue (questions and answers) from expert tutors to develop a set of hinting strategies used to select appropriate hint templates and parameters as responses to classes of questions. CIRCSIM-Tutor does not support online-updating, but is context aware of it’s previous interactions with a student during a single session[12].

We used a strategy similar to CIRCSIM-Tutor to develop a Tensorflow-based chatbot prototype built on Trigram analysis of a “dummy” question and answer corpus.

The CIRCSIM-Tutor paper also provides an evaluation framework for the efficacy of different hinting strategies, and a set of heuristics to select appropriate hint types. This methodology could be used in future semesters to evaluate the hinting strategies learned by our chatbot, and display results in SAGE’s researcher interface[12, pp. 128–134].

## Publication

**[The concept of reference architectures]**
Cloutier, et al. examine reference architectures with the goal of providing a more precise definition of their components and purpose. They propose that the value provided by reference architectures lies in the distillation of (in many cases) thousands of person-years of work, a shared baseline for multiple, often cross-functional teams, and guidance for future work. We will reference the architecture evaluation methodologies and structure / component suggestions put forth by this paper while redeveloping SAGE’s reference architecture included in the feasibility study draft[13].

**[A framework for analysis and design of software reference architectures]**
This paper provides a tool in the form of an analysis and design framework, for the creation of software reference architectures based on three primary dimensions: context, goals, and

design. The paper goes on to define five types of reference architectures into which architectures under analysis can be classified:

1. classical, standardization architectures for use in multiple organizations
2. classical, standardization architectures for use in a single organization
3. classical, facilitation architectures for use in multiple organizations
4. classical, facilitation architectures for use in a single organization
5. preliminary, facilitation architectures for use in multiple organizations

The paper validates the framework by applying it to analysis of 24 reference architectures. We plan to use the framework proposed by this paper to design and evaluate our updated reference architecture[14].

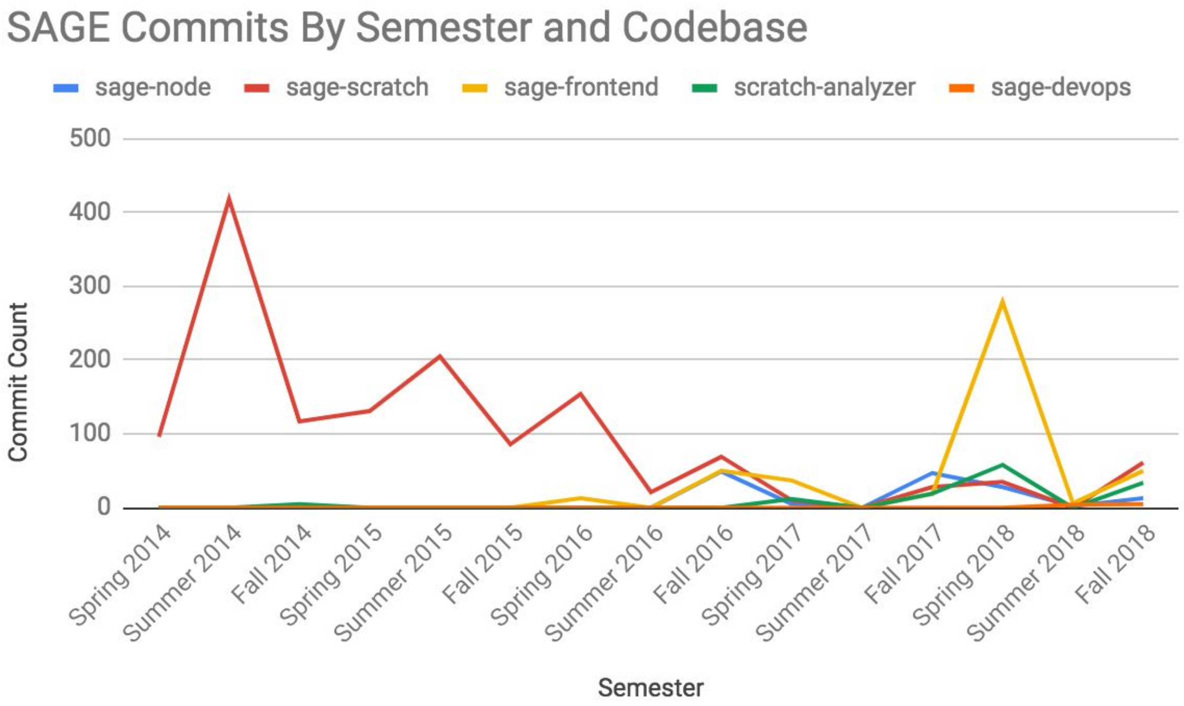
**[The visual display of quantitative information]**

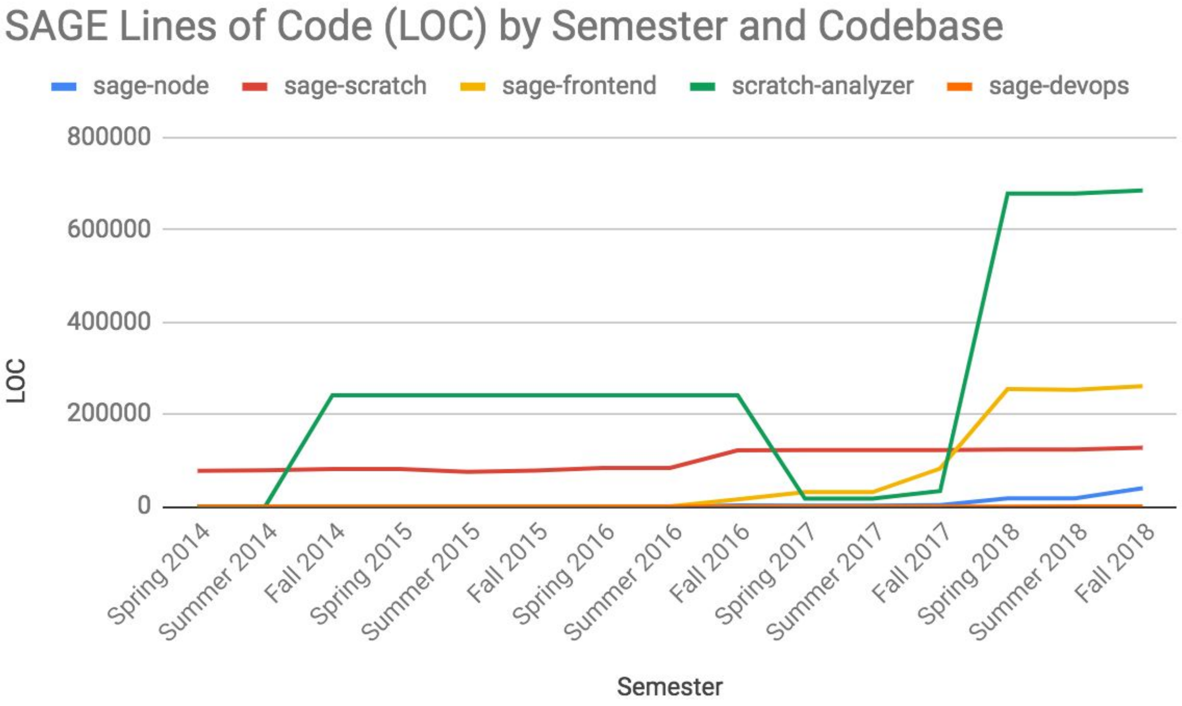
This book is widely used in industry and academia, and provides an exploration and set of recommendations for the design of statistical graphics, charts, tables. It also provides an analysis framework for selecting appropriate data visualizations for a given data set, attempting to optimize for precision, efficacy, and speed of analysis. We will use this book as a reference when evaluating and potentially redesigning the data visualizations in the feasibility study draft[15].

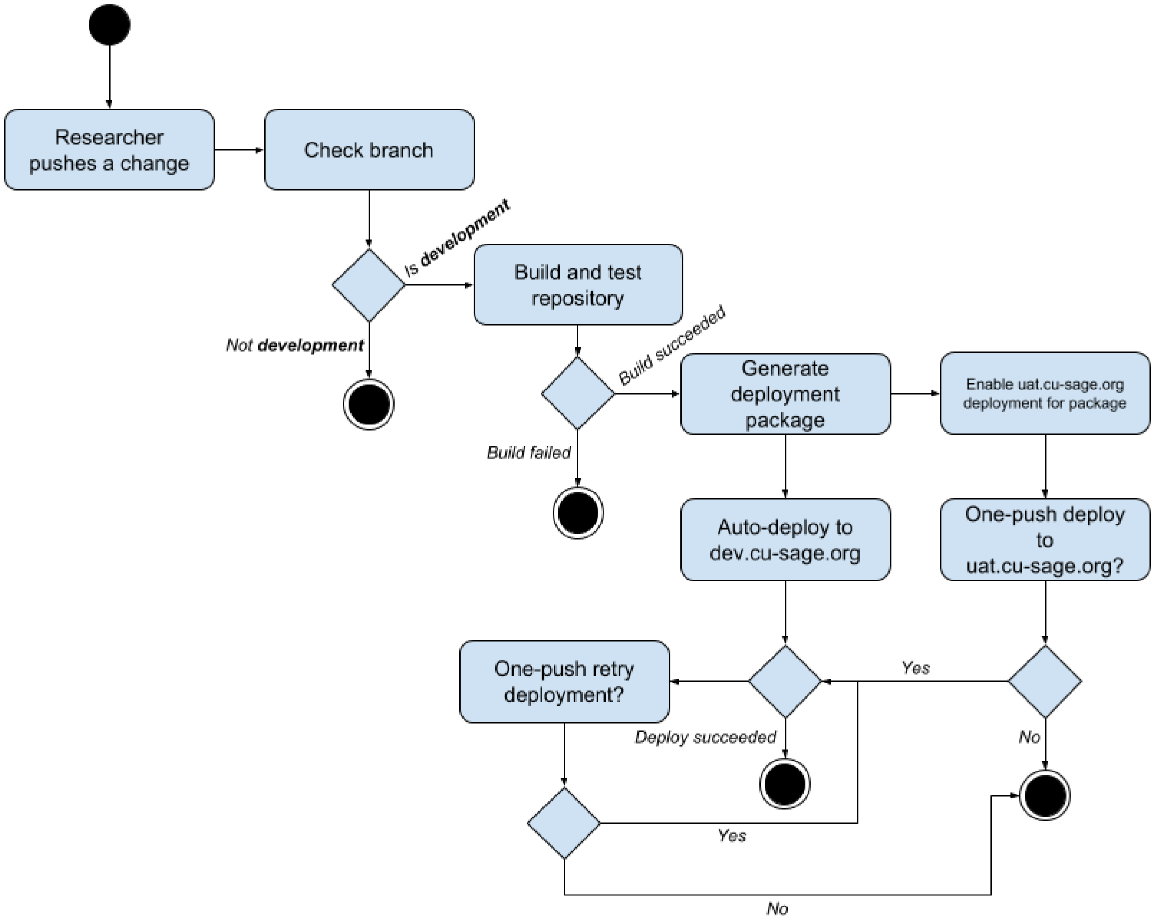
# Accomplishments

Over the course of the semester, our team has accomplished several significant milestones for SAGE. We have provided enhanced stability of the codebase through pull requests and test coverage measurement. We have enhanced the quality of the codebase through automated linting, code standards testing, and documentation[1]. We have integrated and extended the existing intelligent hinting and Parson's Puzzle work in a flexible and sustainable way. Also, we have begun work on SAGE-RA: A Reference Architecture for Gameful Learning[4], which provides a concrete architecture for SAGE, a reference architecture for online Gameful Learning environments, and a validation against code.org, perhaps the most widely used block-based novice programming instruction system available today.

## SAGE Integration: DevOps




SAGE Lines of Code (LOC) by Semester and Codebase
sage-node
sage-scratch
sage-frontend
scratch-analyzer
sage-devops
800000
600000
400000
200000
0
LOC
Spring 2014
Summer 2014
Fall 2014
Spring 2015
Summer 2015
Fall 2015
Spring 2016
Summer 2016
Fall 2016
Spring 2017
Summer 2017
Fall 2017
Spring 2018
Summer 2018
Fall 2018
Semester


Researcher pushes a change
Check branch
Is development
Not development
Build and test repository
Build succeeded
Build failed
Generate deployment package
Enable uat.cu-sage.org deployment for package
Auto-deploy to dev.cu-sage.org
One-push deploy to uat.cu-sage.org?
One-push retry deployment?
Yes
Deploy succeeded
No
Yes
No

## Code Standards and Linting

### 1. Documentation

Documentation has been added to SAGE’s wiki[16] detailing code standards for each of SAGE’s primary programming languages. Documentation also includes guidelines for introducing new style guides for newly adopted languages, and provides details on integrations with our CI / CD systems.

### 2. Standards and Toolsets

We are using the following standards and toolsets:

| **Lanugage** | **Standard** | **Toolset** |
|---|---|---|
| Actionscript | Apache's FlexSDK Coding Conventions[17] | FlexPMD |
| Java | Google Java Style Guide[18] | checkstyle |

| | | |
|---|---|---|
| Javascript / Node.js | standard with semicolons[19] | semistandard |
| Python | PEP 8 style guide[20] | pylint |
| Ruby / Puppet | Puppet 5.0 Style Guide[21] | puppet-lint |
| Other Languages | Shellcheck Style Guide[22] | shellcheck |

3. Build system integration

   Each linting / static analysis tool listed above will be run on every commit to all SAGE repos. At present, semistandard is integrated into the sage-frontend CI/CD system, which will be followed by FlexPMD, checkstyle, pylint, puppet-lint, and shellcheck (by order of priority).

# Gameful Intelligent Tutoring

## Intelligent Hint Integration

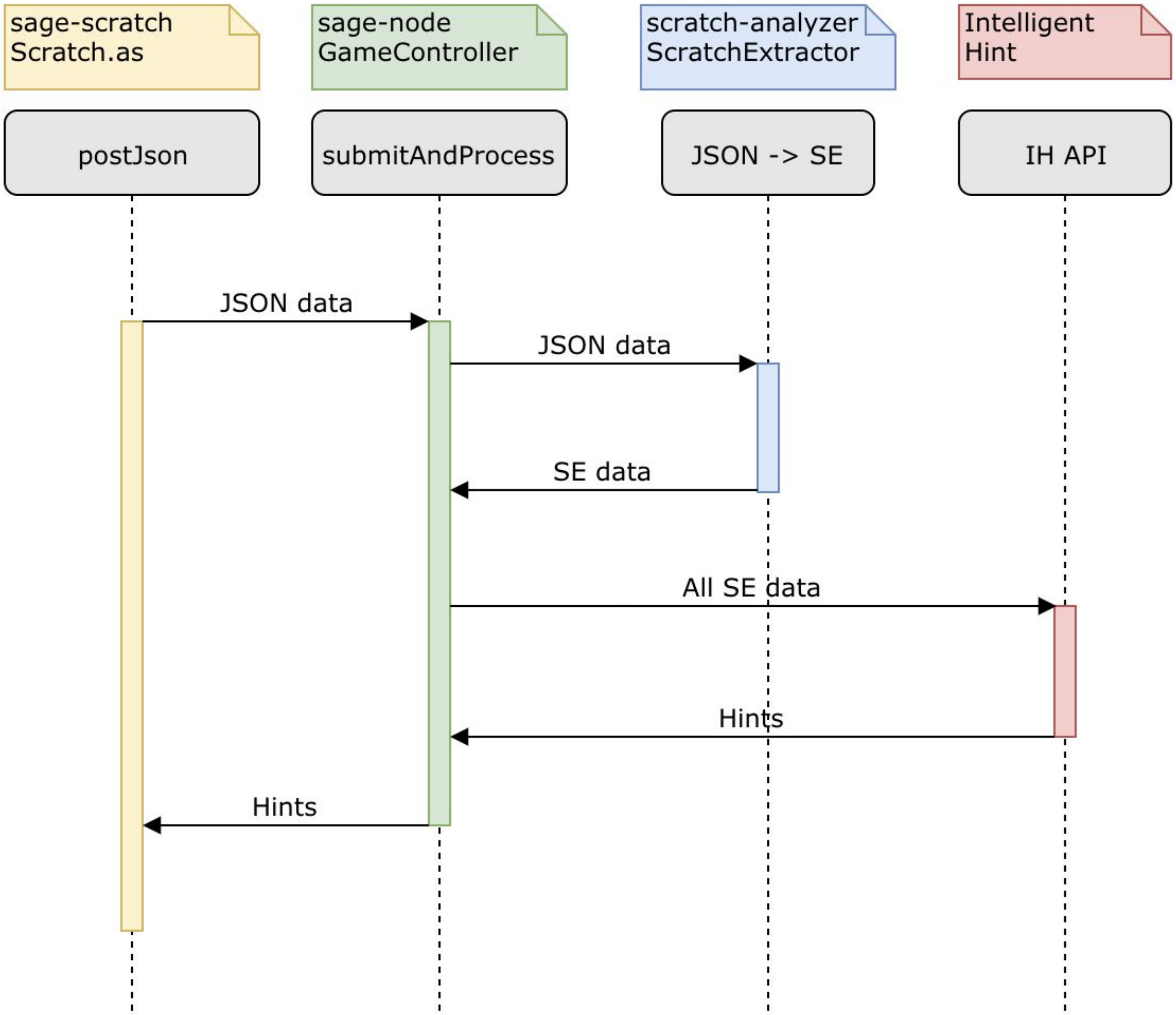
### Data Flow

The integration consists of four parts:

1. sage-scratch: the UI component (ActionScript)
2. sage-node: the information center where data is retrieved and stored (NodeJS)
3. scratch-analyzer Java: the data processor that extracts and analyzes the game data
4. scratch-analyzer Intelligent Hinting: the hint generator (Python)

We dispatch requests and serve data through sage-node so that we only need to maintain one interface for data exchange and one schema for each data collection.

Data flow diagram:



Data flow description:

1. Sage-scratch sends the game snapshot as a JSON string to sage-node on a mouse click event.
2. Sage-node uploads the JSON string as a file to the database.
3. Sage-node converts the JSON string to an SE string with block IDs and another SE string without block IDs and uploads both SE files to the database.
4. Sage-node downloads and sends all SE data associated with the current game to Intelligent Hinting.
5. Intelligent Hinting responds with the updated hints.
6. Sage-node forwards those hints to sage-scratch.

7. Sage-scratch processes the new hint information and resets the blocks to suggest and the hint timer.

## Implementation

1. **Node Utilities**

   We implemented some utilities for the integrated process in sage-node. The new utilities are only used in the game controller for now but can also be applied to other places where such functionalities are required.

   - **Run Java code in sage-node**

     Since we need ScratchExtractor to convert .json files to .se files, we want to run java code in sage-node. We implemented this with the node-java module. Previously, ScratchExtractor could only read and write from the local file system. We modified ScratchExtractor to support parsing a single JSON string and return a single SE string. The java project is exported as scratchJava.jar and added to the sage-node branch. The required files for the java project are also added in sage-node/FilesRequired. In the future, whenever someone modified the java code in sage-scratch, the scratchJava.jar should be updated as well so that the Java utilities are able to run the latest Java code. The java utilities are implemented in app/utils/javaUtils.js. Method extractJson takes a JSON string and returns an SE string.

     The following API was created for testing the extractJson method:

     - ➔ /games/jsonToSe/:showId
       - ◆ Parses a JSON string to an SE string.
       - ◆ The SE string will contain block IDs if :showId is true.

   - **Store files in the database**

     To connect different code areas and get rid of the dependency on the local file system, we will store files in the database using MongoDB's GridFS. In addition to the file content, we can also store important information such as timestamp, student ID, game ID, and objective ID in the metadata. GridFS also allows us to fetch files with metadata. All utilities for file storage have been added to sage-node/app/utils/fileUtils.js. Right now, we have implemented postDbFile, getDbFile and deleteDbFile to directly upload, download and delete files from the database. Moreover, we have added uploadJson, uploadSe and downloadSeFiles which would return Promises so that the data flow can be created as a sequence.

1. uploadJson: upload JSON string to the database as a JSON file.
2. uploadSe: upload SE string to the database as an SE file.
3. downloadSeFiles: download all SE files with the matching metadata as a JSON array.

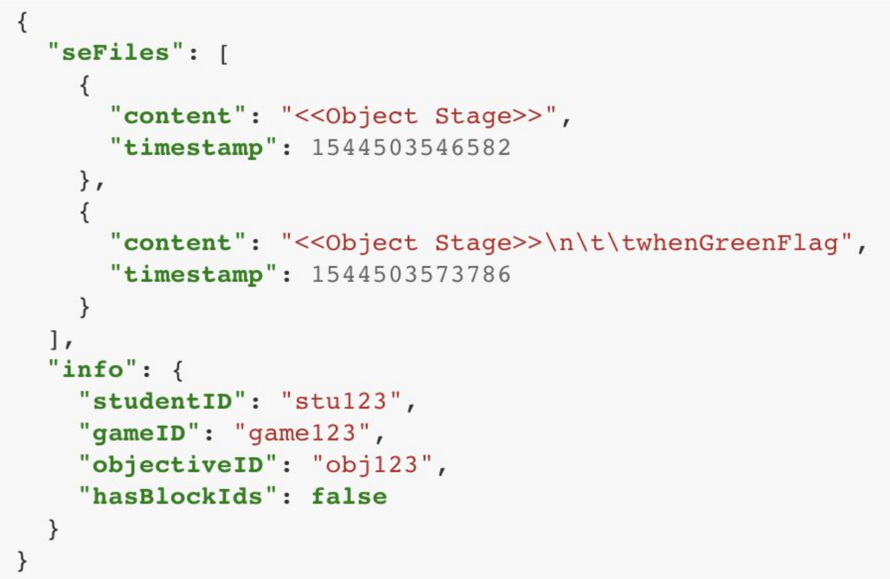
The following APIs were created for testing the file utilities:

- /games/uploadJson/:studentID/:gameID/:objectiveID
    - Uploads a JSON string for a game snapshot.
- /games/uploadSe/:studentID/:gameID/:objectiveID/:hasBlockIds
    - Uploads an SE string for a game snapshot.
    - The SE string contains block IDs if :hasBlockIds is true.
- /games/downloadSe/:studentID/:gameID/:objectiveID/:hasBlockIds
    - Downloads all SE data for a specific game.
    - The SE data will contain block IDs if :hasBlockIds is true.
- /games/file/:filename
    - Downloads a file by filename.
- /games/file/delete/:filename
    - Deletes a file by filename.

2. **Hint Requests and Responses**

Sage-node bundles the contents of all .se files associated with a game session and sends them to the intelligent hint system to request hints. The bundled data is a JSON object returned by fileUtils.downloadSeFiles.

Request example:

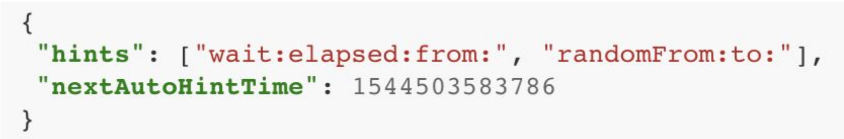


```
{
  "seFiles": [
    {
      "content": "<<Object Stage>>",
      "timestamp": 1544503546582
    },
    {
      "content": "<<Object Stage>>\n\t\twhenGreenFlag",
      "timestamp": 1544503573786
    }
  ],
  "info": {
    "studentID": "stu123",
    "gameID": "game123",
    "objectiveID": "obj123",
    "hasBlockIds": false
  }
}
```

The “seFiles” field stores a list of SE data order by their timestamps. The content of the SE data is an SE string. The common attributes of these SE data can be found in the “info” field. The SE data sent to Intelligent Hint do not contain block IDs as the intelligent hint algorithms only use block names.

We expect two types of response from Intelligent Hint, both with a “hints” field that contains a list of suggested blocks. The type 1 response has an extra field “nextAutoHintTime”, which stores the timestamp when the hints should be shown to the user automatically. Both types of response will be used to replace the blocks to suggest in the scratch game. If the hints list is empty, then no hints will be available to the user after updating the blocks.

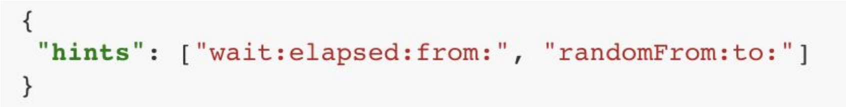
- Response type 1 example:



```
{
 "hints": ["wait:elapsed:from:", "randomFrom:to:"],
 "nextAutoHintTime": 1544503583786
}
```

Hints will be shown to user at nextAutoHintTime automatically or on demand.

- Response type 2 example:



```
{
 "hints": ["wait:elapsed:from:", "randomFrom:to:"]
}
```

Hints will be shown to the user on demand only.

3. **Hint Timing**

   Previously, the hint timing logic was implemented in sage-scratch and was completely separated from the user behavior and the intelligent hint code area, so we were not able to take advantage of the intelligent system to generate smart hint timing. With the new integrated process, we handed the control of automatic hint timing to the intelligent hint system by taking a “nextAutoHintTime” from the hint response and using it to set the hint timer. Also, the previous logic posted the game snapshot every second. But frequent updates will introduce a lot of redundant requests, especially since it is unlikely that the game snapshot changes every second. Therefore, we modified the logic to only post JSON data after a mouse click, when there are potential changes in the snapshot.

   When sage-scratch receives nextAutoHintTime, it resets the hint timer to show the hint at the updated time. Depending on how we generate on-demand hints, we may need a separate object to store automatic hints. For now, on-demand hints and automatic hints are generated by the same algorithm, and the only difference between them is timing.

4. **Hints UI**

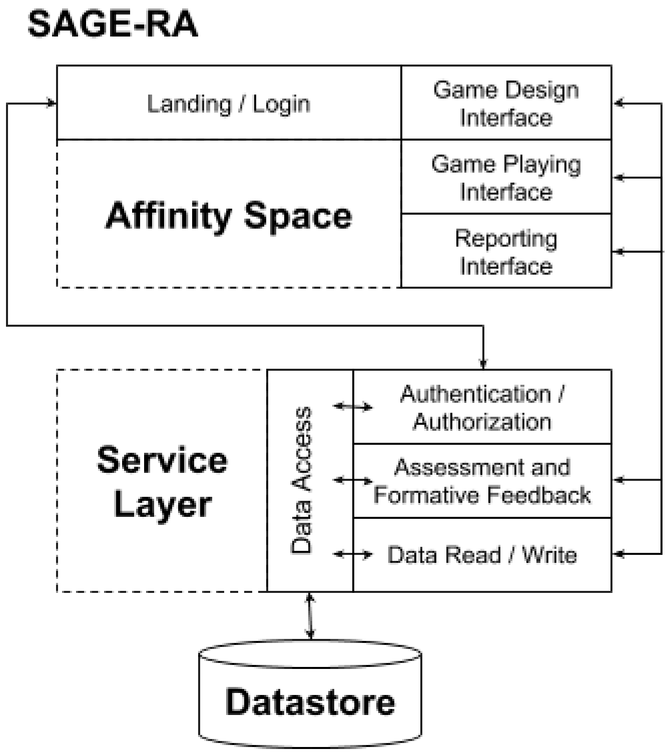
   After receiving hints from the intelligent hint system, sage-node passes them to sage-scratch. Sage-scratch then updates the hints on the BlockPalette and resets the category and block hint timers (with nextAutoHintTime). When a timer goes off or the user asks for an on-demand hint, sage-scratch will shake the suggested categories or blocks. Additionally, we added a hint button for the user to request on-demand hints. When this hint button is clicked, the hints will be shown to the user immediately.

## Limitations

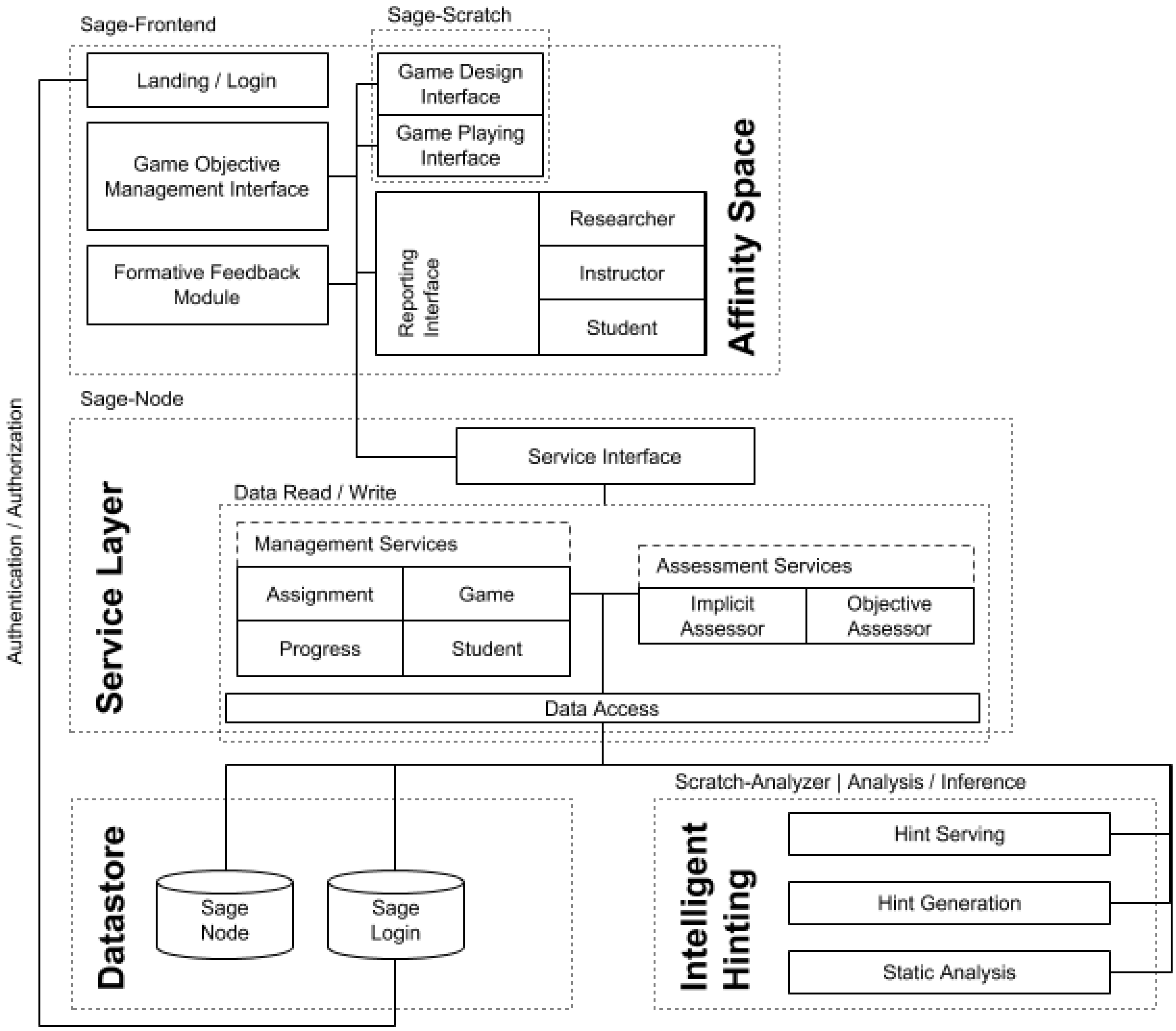
1. The intelligent hint system requires a user type to generate hints. Currently, we have not yet integrated with the user behavior detection system, so the intelligent hint system uses a arbitrary user type.
2. We assume that the game snapshot will only change if there is a mouse click event. But this may change if we record more information than block names in the game snapshots or if more user interaction becomes available.

Fig. 7: DevOps workflow in SAGE

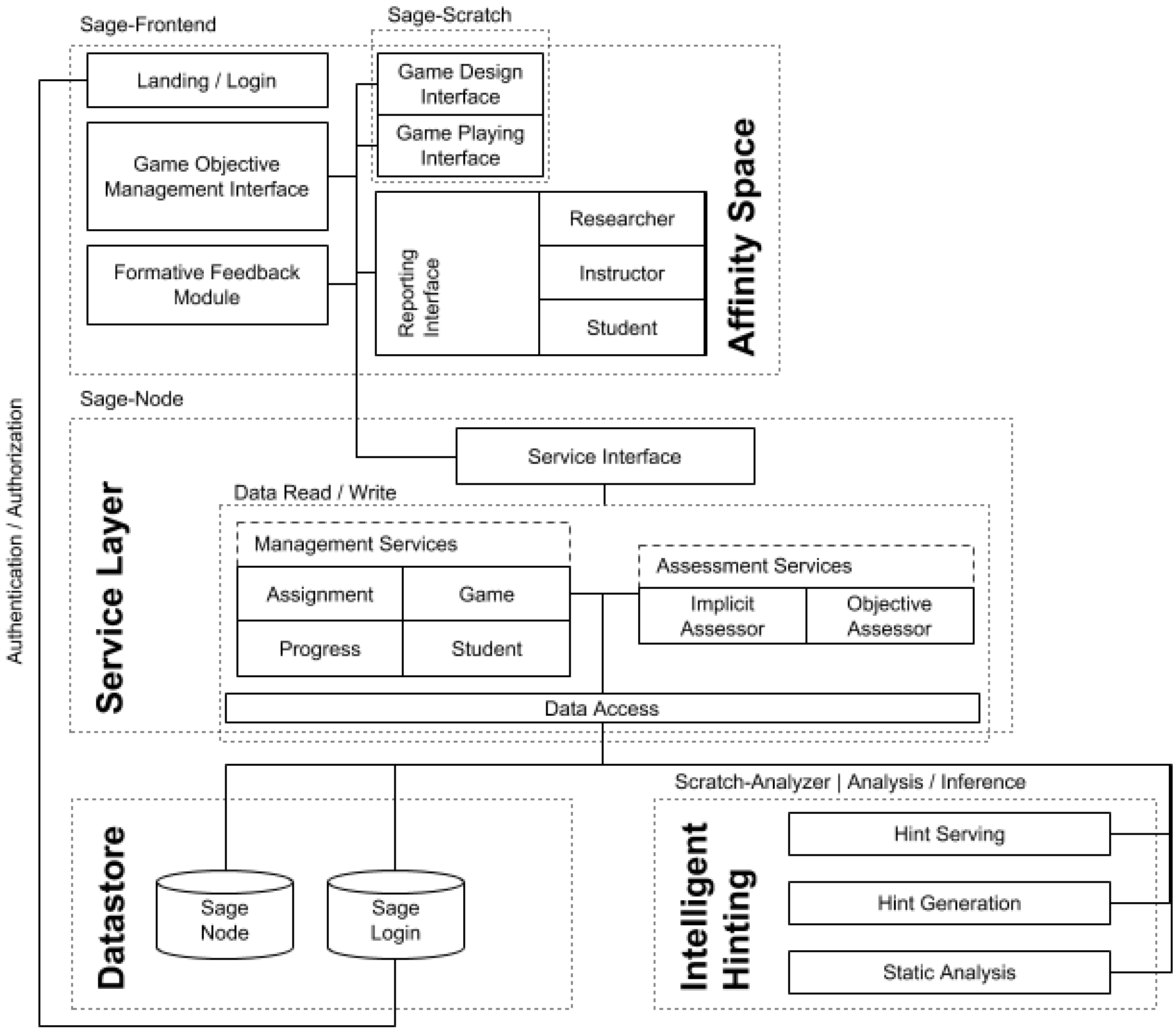
# Publication


SAGE-RA
Landing / Login
Game Design Interface
Game Playing Interface
Reporting Interface
Affinity Space
Service Layer
Data Access
Authentication / Authorization
Assessment and Formative Feedback
Data Read / Write
Datastore

## SAGE (Concrete Architecture)



SAGE (Concrete Architecture)



# Future Work: Next Steps

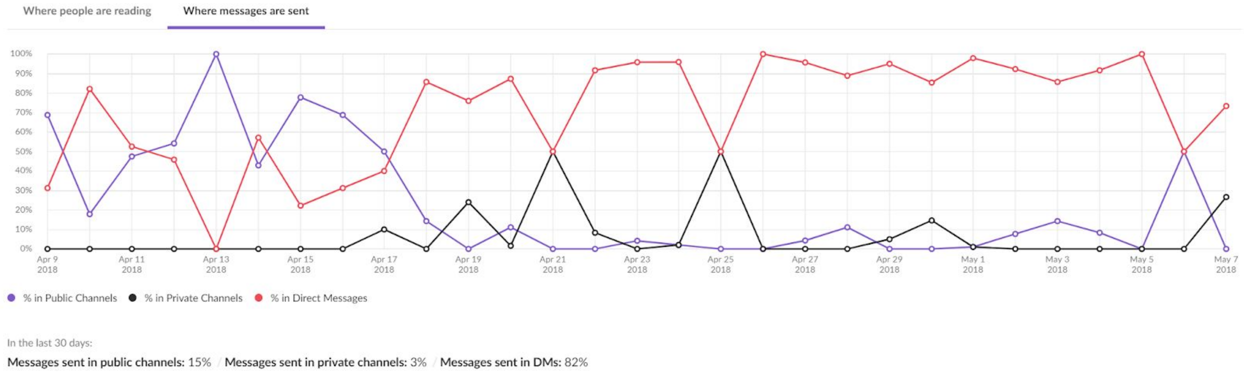
Our work this semester has surfaced a large amount of opportunities for additional work within DevOps, Gameful Intelligent Tutoring, and future SAGE publications. Next steps in each of these research areas include:

1. **Intelligent Hinting - Chatbot POC** - Use our trained model as a decider in an n-gram analyzer to create a proof-of-concept chatbot, that would provide intelligent hinting to students on-demand through a natural language chat interface.
2. **Configuration management** - Automated setup for shared and local dev environments, performed through Ansible, Puppet, or Chef to accelerate future research teams and allow for repeatable environment builds, and configuration-as-code for shared environments (Dev, UAT, Prod).
3. **Interactive Intelligent Hinting Analysis and Framework**
4. **AsUnit testing**

5. **Newman (Postman Collection Runner) integration**
6. **Linting and pre/post-commit hooks**
7. **Test coverage and "publish-on-green"**
8. **SAGE code standards**
9. **Code review integration into the CI pipeline**
10. **Production environment**

    A production environment is not necessary until SAGE is released to end users or research subjects. However, creating infrastructure and implementation plans for a cloud-provider agnostic production environment would improve SAGE's disaster recovery time, and may uncover inefficiencies or undocumented dependencies on the current development and UAT environments in Azure.
11. **Scheduled UAT builds**

    UAT deployments are currently manually triggered. Finding an optimal UAT build schedule and pushing "N-day'ly" builds would reduce the risk that valid builds are accidentally skipped in UAT, and would reduce the overhead on project administrators, who are currently required to manually trigger deployments.
12. **Communication optimization**



In the last 30 days:

Messages sent in public channels: 15% / Messages sent in private channels: 3% / Messages sent in DMs: 82%

    The Slack **#general** channel, to which all researchers are subscribed, had much lower utilization (15-18% of overall messages, according to Slack Analytics) than direct messages (82%) this semester. More utilization of the **#general** channel, in particular to announce teams' progress and feature updates, would improve the visibility of new work across the research team. To further enhance cross-pollination and exposure of new features across teams, messages to **#general** could be generated automatically with every TFS build. Increased shared demos, and ad-hoc demos (via WebEx) of new features, would also improve information sharing within the team.
13. **Project management and WBS improvements:**

    Commits are not currently tied to work items. We should update the researcher workflow to include work item IDs in commits. This is supported by TFS, and would have the added benefit of allowing researchers to close (or otherwise change state) on a work item via a commit message, instead of requiring them to also log into and interact with the TFS work interface.
14. **Use Cases and Personas**

    Some SAGE use cases aren't documented. It would benefit future researchers if a use case / user persona inventory is created to guide future work.
15. **Project management methodology**

    Our project management methodology is not fully formalized or documented. Building an agile project schedule for research in future semesters, with regular deliverables, would improve visibility of work across research teams.  Documenting our project management methodology would reduce the time to productivity for new researchers, and the increased understanding across the team should improve productivity and reduce project management overhead, such as closing WBS tasks, in future semesters.

16. **Intelligent Hint Integration**
    - More Files for Intelligent Hint
      The hint request now contains all the game snapshots. However, for the intelligent hint algorithm to work, we also need to include the complete SEs for the game and other supporting files in the hint request. This extra information will need to be created and stored to the database before the game is open for playing, so perhaps right after the teacher has created the game.
    - Integration with User Behavior Detection
      The user behavior detection system also needs the game snapshots to generate user types, which are also required inputs for the intelligent hint system. By integrating with the behavior detection system, we will be able to calculate user type in real time and thus generate more accurate hints. The future work may find the version of the SE file with block IDs useful, and the SE files of this version are created and stored the database by the current integrated process in sage-node.
    - Hint Timing Algorithm
      The current intelligent hint system is not able to generate a calculated hint timing. We should develop a new algorithm for calculating the hint timing based on user behavior, game type, skill type, etc.
    - Support More Hint Types
      Although the current intelligent hint system only generates automatic hints, the design should be able to support different hints types such as chatbot hints and multilayer hints. Also, we could have a different algorithm to create on-demand hints from automatic hints. Moreover, all available hints are shown at once by shaking together, but we may want other ways to show hints, select one hint at a time based on some priority, and avoid duplicate hints.

# Conclusion

Our work this semester focused on SAGE’s code health and stability as the size and change frequency of the codebase increases, integrating, extending, and surfacing Gameful Intelligent Tutoring and Parson’s Puzzle work from previous semesters, and preparing an initial draft of a reference architecture for future publication, or for use in components of other future SAGE publications.

Code-style checking and documentation[1], protection of mainline code branches through gated pull requests[2], a clean merge of Summer 2018 and Spring 2018’s conflicting Parson’s Puzzles work, and code coverage[3] checking of all primary SAGE codebases, comprized the bulk of our DevOps work, and should improve the time-to-productivity, and stability of SAGE through future semesters.  SAGE-RA, includes our reference, conceptual, and concrete architectures for SAGE, and a validation against code.org’s implementation[4].  Thoughtful implementation of an integration API for SAGE’s existing intelligent hinting engine, and integration with the frontend interface and inference and analyses pipelines, has allowed us to surface Gameful Intelligent

Hinting work done in this and past semesters within the SAGE UI, in a fully-integrated and extensible way, for the first time in the project's history.

# References

[1] "Confluence." [Online]. Available: https://gudangdaya.atlassian.net/wiki/spaces/SAGE/pages/579141633/SAGE+Code+Standards. [Accessed: 17-Dec-2018]

[2] M. M. Rahman and C. K. Roy, "An Insight into the Pull Requests of GitHub," in *Proceedings of the 11th Working Conference on Mining Software Repositories*, Hyderabad, India, 2014, pp. 364–367.

[3] L. E. Lwakatare, P. Kuvaja, and M. Oivo, "Dimensions of DevOps," in *Agile Processes in Software Engineering and Extreme Programming*, vol. 212, C. Lassenius, T. Dingsøyr, and M. Paasivaara, Eds. Cham: Springer International Publishing, 2015, pp. 212–217.

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