Construction of a Digital Exam Grading System using TeX

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About Me

- Yusuke TERADA from Tokyo, Japan
- A private preparatory school teacher for high-school students
- Japanese TeX Development Community
- A contributor to TeXShop development
- Major work: TeX2img [https://tex2img.tech/](https://tex2img.tech/)
TUG 2013: October 23–26, 2013
The 34th Annual Meeting of the TeX Users Group

Graduate School of Mathematical Sciences, the University of Tokyo
3-8-1 Komaba, Meguro-ku, Tokyo, JAPAN
Utilize TeX for promoting operational efficiency in school
2-stage Selection

First Stage

National Center Test for University Admissions

- Examinees: over 570,000 students
- Multiple-choice test
- Automatically scored by computers
- Used as cut-offs for the 2nd stage
2-stage Selection

Second Stage

Exams conducted by individual universities

- Examinees: students who passed the 1st stage (Required score depends on each university)
- Style: descriptive paper test
- Graders: professors at each university
Preparatory Schools

- Privately-run schools which provide education supplementary to public education
- Aim to help students prepare entrance exams
- Conduct practice exams on a regular basis
Specifications of Practice Exams

- Paper-and-pencil exam in a descriptive manner
- Examinees: over 800 students
- Graded by humans
- Assigned time for grading: less than one week
- Fairness is strictly required
- Graders correct answers and add comments
- Return feedback to examinees
1. (B) few

2. (1) I don’t think this story has being read by no one of you yet.

    (2) We won’t be able to arrive there by five o’clock.

    (3) The invention had been possible by his big effort.

    (4) I don’t mind being told a lie, but I don’t like to tell a lie.

    (5)(a) Everyone found it difficult to understand my picture.

    (5)(b) Your grandfather saw this, he would be pleased to your effort.

5. (A) 彼女はついに、彼らが老人が庭とされないようにしているを手伝うために車を止めてほしいと言ったのだと理解した。

    (B) 私が一日中誰かがいるところから

        次の日には彼女の顔を忘めるかも知れない。

    (C) これは人気のクラスで、技術は子ども達が学ぶにも簡単で

6. (B) 背が小っちゃ自分にはどうしようもない。

    (C) name
Pile of answer sheets

1. few
2. (a) I don't think this story has been read.
   (b) No one of you yet.
   (c) Five o'clock.
   (d) The invention had been possible. His big effort.
   (e) I don't mind being told a lie, but I don't like to tell a lie.
   (f) Everyone found it difficult to understand my picture.
   (g) Your grandfather saw this, he would be pleased to your effort.

6. (A) 5
   (B) 6
Before TeX

1. Sort answer sheets by hand
2. Divide a pile of answer sheets into some piles
3. Graders score their assigned problems in parallel
4. Exchange the piles to each other
Divided piles
Phase 3

Grader 1

Grader 2

Grader 3
Before TeX

5. Transcribe hand-written scores into Excel

6. Cross-check the transcribed scores visually
5. Transcribe hand-written scores into Excel

6. Cross-check the transcribed scores visually

Insanely Inefficient
Before TeX

5. Transcribe hand-written scores into Excel

6. Cross-check the transcribed scores visually

Improving efficiency using IT is imperative!
Requirements for the New Digital Grading System

- Paper-and-pencil style must be maintained.
- Multiple graders should be able to score in parallel on the digital system.
- Privacy and fairness should be secured.
- The system must be run on macOS/iOS.
- Feedback to examinees should be returned in paper.
Solution

- Construct a Digital Exam Grading System
- Utilize TeX as a PDF manipulation tool
TeX system as a PDF manipulation tool

- pdfTeX has a lot of powerful primitives that manipulate PDF since early times.
- Recently (x)dvipdfmx has been enhanced in terms of PDF manipulation.
Recent enhancements of (x)dvipdfmx

- `extractbb` is automatically invoked when needed. (TL2015)
- `page` option of `\includegraphics` is supported. (TL2015)
- `pagebox` option of `\includegraphics` is supported. (TL2016)
- `\includegraphics` supports direct input of Adobe Illustrator files. (TL2014)
- `pdfpages` package supports (x)dvipdfmx. (TL2015)
- (x)dvipdfmx supports rotated PDF pages. (TL2018)
\includegraphics[page=2, pagebox=artbox, viewport=0 20 40 80, scale=2.5, clip] {foobar.pdf}

- **page**: PDF page number to include
- **pagebox**: mediabox/cropbox/trimbox/bleedbox/artbox
- **viewport**: bounding box relative to **pagebox**
- **scale**: magnification scale factor
- **clip**: hide outside of bounding box
The workflow of the newly built digital grading system using TeX
Step 1: Prepare Answer Sheets

Make individualized answer sheets using TeX
2019年度 第1回校内模試 中2 英語 記述解答用紙

1 (B) ________________
(C)

2
(1) ________________

(2) ________________

(3) ________________

(4) ________________

(5)(a) ________________

(5)(b) ________________

1 計

2 計

5
(A) ________________

(B) ________________

(C) ________________

(A) 計

(B) 計

(C) 計

6
(B) ________________

(C) ________________

6 計

欄外に記入したものは採点されないので注意すること
Collection of rule's
Criterial marks used for image correction

Drawn with TikZ
**qr code package**

- QR code generator written in pure TeX
- Developed by Anders Hendrickson
- Included in CTAN and TeX Live
qrcode package

- QR code generator written in pure TeX
- Developed by Anders Hendrickson
- Included in CTAN and TeX Live
- Each block is drawn with `\rule`
Step 2: Scan answer sheets

After conducting an exam, scan the collected answer sheets and obtain scanned-PDF.
1. (B) few

(C) 最も小さい電波を送信するアンテナを

2. (1) I don’t think this story has being read
    no one of you yet.

(2) We won’t able to arrive there by
    five o’clock.

(3) The invention had been possible by
    his big effort.

(4) I don’t mind being told a lie, but I don’t
    like to tell a lie.

(5a) Everyone found it difficult to understand
    my picture.

(5b) Your grandfather saw this, he would
    be pleased to your effort.

5. (A) 彼女はうつに、彼らが老人が庭をきれいにして
    いるのを手伝うために車を止めてほしいと言ったのだと理解した。

(B) 私が一日中誰かといっただけ
    次の日には、彼らの顔を忘れすこともない。

(C) これほんやりのクラスで、技術は子ども達が
    受け入れても簡単で

6. (B) あが小いらは自分にはどうしようもない。

(C) name
Step 3: Read, sort and correct images

- Identify the examinee of each sheet based on the embedded QR code
- Sort images by the numbers encoded in the QR codes
- Correct the scanned-images based on the criterial marks
  - Paper orientation
  - Translation
  - Rotation
  - Distortion
DyNAMiKS

Dynamic Asynchronous Mark-interpretation Kernel System

- Developed by Mitsuhiro DAIMON (Physics teacher at our school)
- Written in Swift and Objective-C
- Run natively on macOS
- Use macOS Cocoa API for PDF handling
- Adopt OpenCV as its image-processing engine
- Being developed on GitHub (but currently not open-sourced, sorry.)
Column Editorでマージン部分にもカラム設定したい

previewモードにおいてMeasured rectangle: [nan, nan]となる

無マークのものの塗りが1になる

scancropにおける同一ファイル名指定

scancropにおける不適切な出力拡張子

処理対象ページ指定機能

normalモードのパラメータ最適値を探す

pdfscancropモード実装

選択範囲の色

OpenCVが実行時に落ちる問題

JSONパスできない
Recognize images with high accuracy
Step 4: Make grading forms

By using

\includegraphics[page=...,viewport=...]

- Split each answer sheet
- Make grading forms
1. **Few**

2. (1) I don't think this story has being read no one of you yet.

   (2) We won't be able to arrive there by five o'clock.

3. The invention had been possible by his big effort.

4. I don't mind being told a lie, but I don't like to tell a lie.

5. (a) Everyone found it difficult to understand my picture.

   (b) Your grandfather saw this, he would be pleased to your effort.

   (A) 彼女はついに、彼らが老人が庭をさしきれているのを手伝うために車を止めてほしいと言ったのだと理解した。

   (B) 私が一日中誰かいのことがだきたたら次の日には彼らの顔を忘れてかも知れない。

   (C) これは雅気のクラスで技術は子ども達が学ぶにも簡単で。

6. (B) 体重が小さいのは自分にはどうしようもない。

   (C) name

---

欄外に記入したものは採点されないので注意すること。
(5)(a) Everyone found it difficult to understand my picture.

(5)(b) Your grandfather saw this, he would be pleased to your effort.

<table>
<thead>
<tr>
<th>第 2 関 (5)(A) 得点</th>
<th>0点</th>
<th>1点</th>
<th>2点</th>
<th>3点</th>
<th>4点</th>
</tr>
</thead>
<tbody>
<tr>
<td>第 2 関 (5)(B) 得点</td>
<td>0点</td>
<td>1点</td>
<td>2点</td>
<td>3点</td>
<td>4点</td>
</tr>
</tbody>
</table>

【採点基準（採点官用）】

(a) ① □ 「どうやら…することに苦しんでいる・苦労している」(3点)
     □ 「どうやら」の表現での減点は2点まで減点。
     □ 「するのに苦労する」で trouble doing の形でのミスも2点まで減点。
     ② □ 「僕の絵を理解する」(1点)

(b) ① □ 仮定法のミス・「きっと」の脱落 (2点)
     ② □ 「…に満足する」(2点)：「満足する」の表現ミスに関しては2点減点。
     □ effort の語に関しては1点まで減点。
Import only specific problems assigned to each grader

(5)(a) Everyone found it difficult to understand my picture.

(5)(b) Your grandfather saw this, he would be pleased to your effort.
Grading Form

Remove name and import QR code

For privacy and fairness
Grading Form

Distinguish background by color

White area: feedback
Gray area: note

\pagecolor{black!20!white}
(5a) Everyone found it difficult to understand my picture.

(5b) Your grandfather saw this, he would be pleased to your effort.
Step 5: Perform grading with iPad

iPad Pro + Apple Pencil + GoodNotes

Hardware

Software
After grading

(5)(a) Everyone found it difficult to understand my picture.

If your grandfather saw this, he would be pleased with your effort.

(5)(b) [Redacted]

【採点基準（採点公用）】

(a) ①「どうやら…することに苦しんでいる・苦労している」(3点)
    □ 「どうやら」の表現での減点は2点まで減点。
    □ 「するのに苦労する」で trouble doing の形でのミスも2点まで減点。
    ②「僕の絵を理解する」(1点)

(b) ① 仮定法のミス・「きっと」の脱落(2点)
    □ 「…に満足する」(2点)：「満足する」の表現ミスに関しては2点減点。
    □ effort の語に関しては1点まで減点。
Write feedback within white area

(5)(a) Everyone found it difficult to understand my picture.

IF
(5)(b) Your grandfather saw this, he would be pleased with your effort.

Fill scores

(a)
1. «どうやる…することに苦しんでいる・苦労している」(3点)
2. «どうやる」の表現での減点は2点まで減点。
   □ 『するのに苦労する』で trouble doing の形でのミスも2点まで減点。
3. 「僕の絵を理解する」(1点)

(b)
1. 仮定法のミス・「きっと」の脱落(2点)
2. 「…に満足する」(2点):「満足する」の表現ミスに関しては2点減点。
   □ effort の語に関しては1点まで減点。
Step 6: Export grading forms as PDF
Step 7: Read scores with DyNAMiKS

Collect \((\text{examinee number, score})\) data
Step 8: Restore answer sheets

Restore answer sheets to return from grading forms
Grading forms of a single examinee

Merge feedback areas into one sheet
1. (B) 新

2. (1) I don't think this story has been read yet.
(2) We won’t able to arrive there by five o’clock.
(3) The invention had been possible by his big effort.
(4) I don’t mind being told a lie, but I don’t like to tell a lie.
(5)(a) Everyone found it difficult to understand my picture.
(5)(b) Your grandfather saw this, he would be pleased to your effort.

5. (A) 彼女はついに、彼らが老人が庭をきれいにして
一番手伝うために車を止めほしいと言ったのだと理解した。
(A) 計 6/6

(B) 私が一日中誰かと会うことができたら
次日には彼の顔を忘れては知れない。
(B) 計 4/5

(C) これは人気のクラスで、技術は子ども達が
学ぶことも簡単で
→ ×
due to A and B ××
(C) 計 4/6

6. (B) 井が小さいから自分にはどうしようもない。
(C) 名

6 計 11

第3問計 14 第4問計 13 合計得点 72
Each area is pasted from grading forms with \includegraphics
Examinee's name is restored from the original PDF with \includegraphics
TeX overprints score digits read by DyNAMiKS on the sheet image
Step 9: Print sheets and return feedback

- Print the restored answer sheets in color
- Return them to students in classrooms
1. 個人成績表

<table>
<thead>
<tr>
<th>番号</th>
<th>単元</th>
<th>得点</th>
<th>平均点</th>
<th>優良点</th>
<th>順位</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>力学</td>
<td>10</td>
<td>9.8</td>
<td>50.4</td>
<td>31</td>
</tr>
<tr>
<td>2</td>
<td>電磁気学</td>
<td>8</td>
<td>9.5</td>
<td>46.7</td>
<td>N/A</td>
</tr>
<tr>
<td>3</td>
<td>熱力学</td>
<td>2</td>
<td>7.4</td>
<td>39.6</td>
<td>N/A</td>
</tr>
</tbody>
</table>

合計 | 20   | 26.7 | 44.4   | N/A   |

累計

【単元別累計成績】

<table>
<thead>
<tr>
<th>単元</th>
<th>物理</th>
<th>電気学</th>
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</thead>
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<tr>
<td>13</td>
<td>8</td>
<td>9.5</td>
</tr>
</tbody>
</table>

累計 | 9.7  | 11.4   | 44.5   |

※順位は40位まで表示され、それ以下の場合は「N/A」表示されます。
Analysis sheet

1. 個人成績表

<table>
<thead>
<tr>
<th>成績</th>
<th>番号</th>
<th>単位</th>
<th>得点</th>
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<th>優等値</th>
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<td>9.5</td>
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<tr>
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<td>20</td>
<td>26.7</td>
<td>44.4</td>
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</tbody>
</table>

累計成績

| 合計 | 24.0 | 30.3 | 43.4 | N/A |

【単元別累計成績】

<table>
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<tr>
<th>単位</th>
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<th>対幕</th>
<th>難易</th>
<th>順位</th>
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<td>12.9</td>
<td>56.1</td>
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</tr>
</tbody>
</table>

Automatically generated by TikZ + tcolorbox
Workflow Summary

1. Make individualized answer sheets by TeX and conduct an exam.
2. Scan the answer sheets into PDF.
3. Sort and correct the scanned-PDF with DyNAMiKS.
4. Split them and generate grading forms by TeX.
5. Perform grading with iPad Pro + Apple Pencil + GoodNotes.
6. Read scores by DyNAMiKS.
7. Restore answer sheets and overprint scores by TeX.
8. Generate analysis sheets by TikZ + tcolorbox.
9. Print sheets and return them to students in paper.
All-in-One App
macOS GUI App
Result

- Time for grading: shortened
- Fairness: enhanced
- Risk of losing answer sheets: disappeared
- Transcription by hand: no longer necessary
Result

- Time for grading: shortened
- Fairness: enhanced
- Risk of losing answer sheets: disappeared
- Transcription by hand: no longer necessary

Efficiency: improved
Difficultly

"Too many images in a document"

× 800 students
/* Migrated from pdfobj.h. Those are not PDF object related... */
#define MAX_IMAGES 5000 /* This may be enough */

texk/dvipdfm-x/pdfximage.h

if (xobj_id > MAX_IMAGES - 1) {
    spc_warn(spe, "Too many images...");
    pdf_release_obj(fspec);
    if (ident)
        RELEASE(ident);
    return -1;
}
/* Migrated from pdfobj.h. Those are not PDF object related... */
#define MAX_IMAGES 5000 /* This may be enough */

Not enough!

if (xobj_id > MAX_IMAGES - 1) {
    spc_warn(spe, "Too many images...");
    pdf_release_obj(fspec);
    if (ident)
        RELEASE(ident);
    return -1;
}
This limitation was abolished at TeX Live 2018
Future Work

Handwritten Digit Recognition
Future Work

MNIST

\[
\begin{array}{c}
60114473733752322967 \\
3375731272364122695 \\
18743673047924186962 \\
46850122476559263540 \\
13235012072684336357 \\
22453700733310091433 \\
\end{array}
\]
Future Work

Our digits

MNIST
Conclusion

- TeX is useful also as a **PDF manipulation tool**.
- TeX has enormous potential to **automate daily tasks** and **enhance efficiency**.
- Explore further utilization of TeX as an **automation tool**!