Real-Time Data-Driven Interactive Rough Sketch Inking
— SUPPLEMENTAL MATERIAL —

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We present an in-depth report of our user study and additional results of our **Smart Inker** approach. This document is intended as a complement to the technical paper.

1 USER STUDY REPORT

We report on the user study conducting during the evaluation of our approach.

1.1 Design

We designed the user study such that all participants would ink 10 images, 5 with Clip Studio Paint Ex and 5 with Smart Inker, and measure the time it takes each user to ink each rough sketch. Furthermore, we designed it such that all images are inked the same amount of times with both Professional Tools (PT) and Smart Inker. With these two restrictions and a fixed number of participants decided ahead of time, for each user, we randomly choose what images they would ink with which approach, and the order in which they would be inked. A total of 10 users participated and an overview of the order they inked the rough sketches in is shown in Table 1. All the users are remunerated for their participation in the user study. After the user inks all 10 images, they are given a survey to fill out with ten questions.

We did not opt for a pairwise design as we found that repeating the same image twice with a single user led to a considerable bias depending on the order they were inked in, *i.e.*, the first time inking an image takes significantly more time with respect to the second time inking the same image.

1.2 Clip Studio Paint Ex

Clip Studio Paint Ex[1] is software specialized for illustration and, in particular, creation of comics. It contains extensive features for inking, and it particular, removes jitters from the digital pen strokes with improved responsiveness. This professional software package is what we compared Smart Inker to and we abbreviate as Professional Tools (PT).

1.3 Hardware

We perform the user test using a Wacom MobileStudio Pro 16, which is a professional mobile pen computer designed for illustration. It comes both with a pen with pressure sensitivity and employs a large 16" touch screen. We note that while Clip Studio Paint Ex uses this pressure sensitivity, our approach does not.

[1] https://www.clipstudio.net/en

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Table 1. Order in which each of the users performed the user test. Asterisk indicates the particular image was inked using Clip Studio Paint Ex.

User	Order
User 1	2*, 9, 3, 4, 7, 1, 8*, 6*, 5*, 10*
User 2	7*, 5, 4*, 8, 9, 10*, 2, 3*, 6*, 1
User 3	10, 3*, 2*, 9*, 6, 7*, 5, 1*, 8, 4
User 4	9, 5*, 8*, 6, 2*, 7, 10*, 4*, 1, 3
User 5	10*, 5*, 2, 3, 1*, 4, 8*, 9, 7, 6*
User 6	2, 1*, 4*, 3, 7, 9*, 5*, 10, 8*, 6
User 7	1*, 9*, 6*, 10, 4, 2, 3*, 8, 5, 7*
User 8	8, 4*, 1, 5, 6, 9*, 10, 2*, 7*, 3*
User 9	7*, 2, 3*, 6, 1*, 8, 9*, 5, 4*, 10
User 10	6*, 5*, 4, 2*, 8*, 10*, 3, 1, 7, 9

1.4 User Explanation

For each user, we briefly explain both the usage of Clip Studio Paint Ex and our approach. For Clip Studio Paint Ex, we set up the image, and select the "G-pen" inking brush with a default size of 10, although we allow the users to change the brush and brush size. Additionally, the users are able to rotate, zoom, and translate the illustration easily with their fingers, making it very easy to ink with. We also show them how to do other standard operations like undo and redo. For our approach, we show them the basic usage of the three main tools: *inker pen*, *inker brush*, and *smart eraser*, and teach them how to change some visualization options such as the transparency of the rough sketch. Users are also taught how to undo and redo actions. Finally, for both approaches, we give the users 2 minutes to practice before starting the evaluation.

As guidelines for inking, we tell the users to maintain fidelity to the original drawing, while correcting obvious mistakes, *e.g.*, connect disconnected lines or removing scaffolding lines. We also mention explicitly that tone and pencil shading should not be conserved.

1.5 Results

To complete the user study, including explanation, preparation and inking the 10 images, each user took an average of 2.8 hours, with the fastest user being a bit over 2 hours, and the slowest user being near 5 hours. The full results of the survey are summarized in Fig. 1. We can see that out of the 10 individuals, three profess to have significant drawing experience, three have some drawing experience, and four are complete amateurs. Almost all of the users find our approach easier, with one user preferring Clip Studio Paint Ex, and one finding both equally easy. Half of the users find their results with our tool good and found the tool easy to use. Of the three tools, the *inker brush tool* was found the easiest to use with the *inker pen tool* being the hardest, although even then 4 people found it easy to use. All users believe with more time they could master Smart Inker and that it would be a beneficial addition to professional software such as Clip Studio Paint Ex.

The amount of time taken by each user for each image is shown in Table 2. A graphical representation is shown in 2. We can see that, as expected, there is large variation between users and images due to the nature of the task.

We compare the timings between Clip Studio Paint Ex and Smart Inker with the Mann-Whitney U test [1], a non-parametric statistical test, with the null hypothesis being that timing with both approaches have equivalent medians, and the alternative hypothesis being that they do not (two-tailed test). Unlike the commonly used t-Student test, it

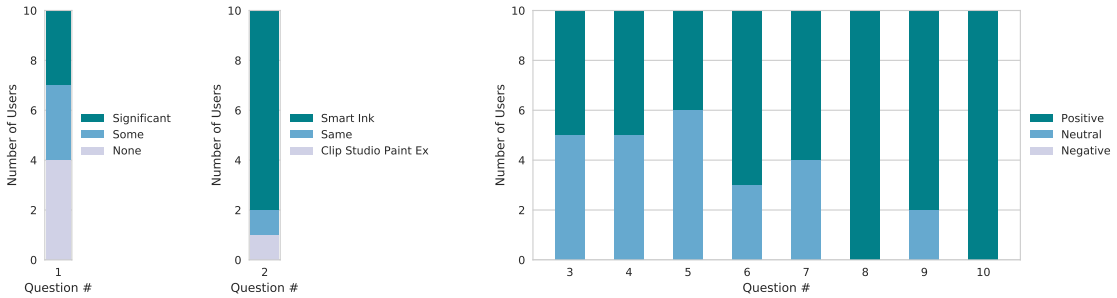


Fig. 1. Summary of the answers of the user survey for each of the ten questions which are the following:

(1) How much experience do you have with drawing and illustration? (none, some, significant)
(2) Which tool is was easier to use? (Clip Studio Paint Ex, same, Smart Inker)
(3) What do you think of the results you obtained with Smart Inker? (poor, fair, good)
(4) How easy was Smart Inker to use? (hard, fair, easy)
(5) How easy was the Smart Inker inker pen tool to use? (hard, fair, easy)
(6) How easy was the Smart Inker inker brush tool to use? (hard, fair, easy)
(7) How easy was the Smart Inker smart eraser tool to use? (hard, fair, easy)
(8) Given enough time to practice, do you feel that Smart Inker is a tool you could become efficient with? (no, maybe with effort, yes)
(9) If yes, how long do you think it would take? (long time, some time, little time)
(10) Should Smart Inker be added to programs like Clip Studio Paint Ex, would it help people with their work? (no, I don't know, likely)

Table 2. Full timing details of the user study. Time is shown in seconds.

	Clip Studio Paint Ex										Smart Inker									
Image #	1	2	3	4	5	6	7	8	9	10	1	2	3	4	5	6	7	8	9	10
User 1		301	539		199	188		73			82			158			148		127	546
User 2	579	518		567		395				697			367		249		435	200	256	
User 3	545			564	445		2699		1225			357	917			540		613		455
User 4		730	1969		778			448		779	236			223		163	487		213	
User 5		408	1137			399	2375	202			447			446	572				677	757
User 6			1172				3410	198	1054	782	283	301		347	748	367				
User 7	786			875		794	6571		2841			338	734		266			241		413
User 8	589			614	489				1745	396		209	345			158	376	125		
User 9	455			453			1769		978	473		325	603		390	500		318		
User 10		1098	1638		602	699		309			165			226			223		231	230
median	579	518	1172	567	489	399	2699	202	1225	697	236	325	603	226	390	367	376	241	231	455
mean	590	611	1291	614	502	495	3364	246	1568	625	242	306	593	280	445	345	333	299	300	480

does not make the assumption of normally distributed data and is thus applicable to data with outliers such as the data we have obtained in our user study. We obtain a U statistic of 1995.0, which corresponds to a p-value of 2.589×10^{-7}, indicating that with very high certainty (over 99.999% probability) we can reject the null hypothesis, and accept the alternate hypothesis that the median values are different. The global speed-up between all images is of 1.8×.

We also show an image-by-image breakdown in Table 3. We can see that for individual images, 6 of the 10 images shown statistical difference in distributions with a significance of $\alpha = 0.1$. Of the tests with statistical significance we see speed-ups of between 1.6× and 7.2×.

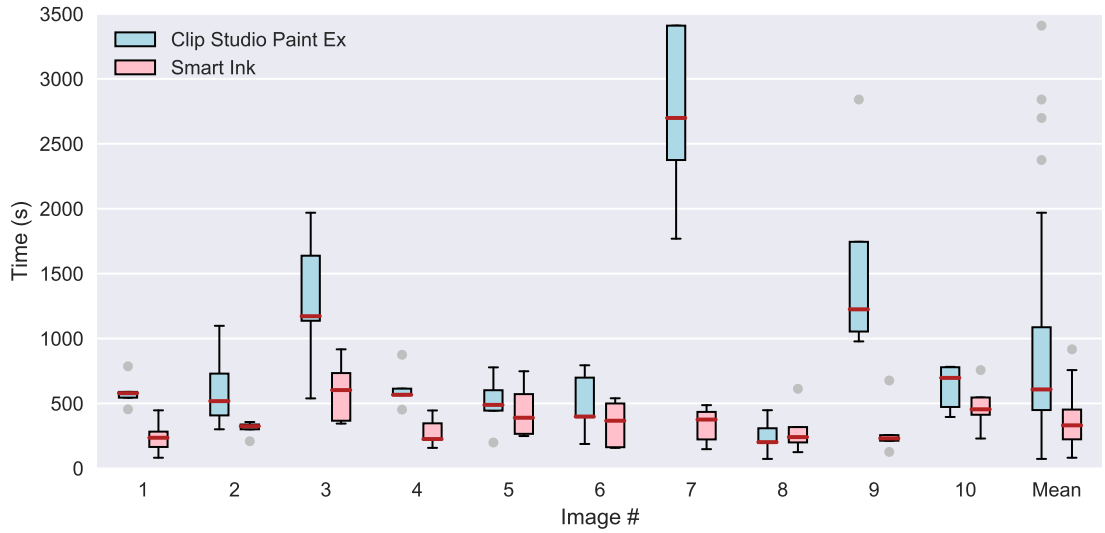


Fig. 2. Timing information for inking each image with different approaches. We plot the results using box plots with the median highlighted in dark red. Outliers are shown in dark gray. We show individual results for each image and the mean results for all the images.

Table 3. Break down of the timing comparison by image. We compare the median interaction times between Clip Studio Paint Ex and Smart Inker and show the speed-up obtained by our approach. We perform a Mann-Whitney U test for each image, comparing whether the two medians are significantly different and show in bold the p-values with a significance of $\alpha = 0.1$.

	Median Value (s)			Mann-Whitney U Test	
Image	Clip Studio Paint Ex	Smart Inker	Speed-up	U statistic	p-value
Image 1	579	236	2.5×	25.0	**1.219e-02**
Image 2	518	325	1.6×	21.5	**7.491e-02**
Image 3	1172	603	1.9×	22.0	**6.010e-02**
Image 4	567	226	2.5×	25.0	**1.219e-02**
Image 5	489	390	1.3×	15.0	6.761e-01
Image 6	399	367	1.1×	18.0	2.963e-01
Image 7	2699	376	7.2×	25.0	**1.219e-02**
Image 8	202	241	0.8×	10.0	6.761e-01
Image 9	1225	231	5.3×	25.0	**1.219e-02**
Image 10	697	455	1.5×	18.0	2.963e-01
mean	608	331	1.8×	1995.0	**2.859e-07**

Finally, we show the images used in the user test and example results of inking both with Clip Studio Paint Ex and Smart Inker in Figures 3 to 12.

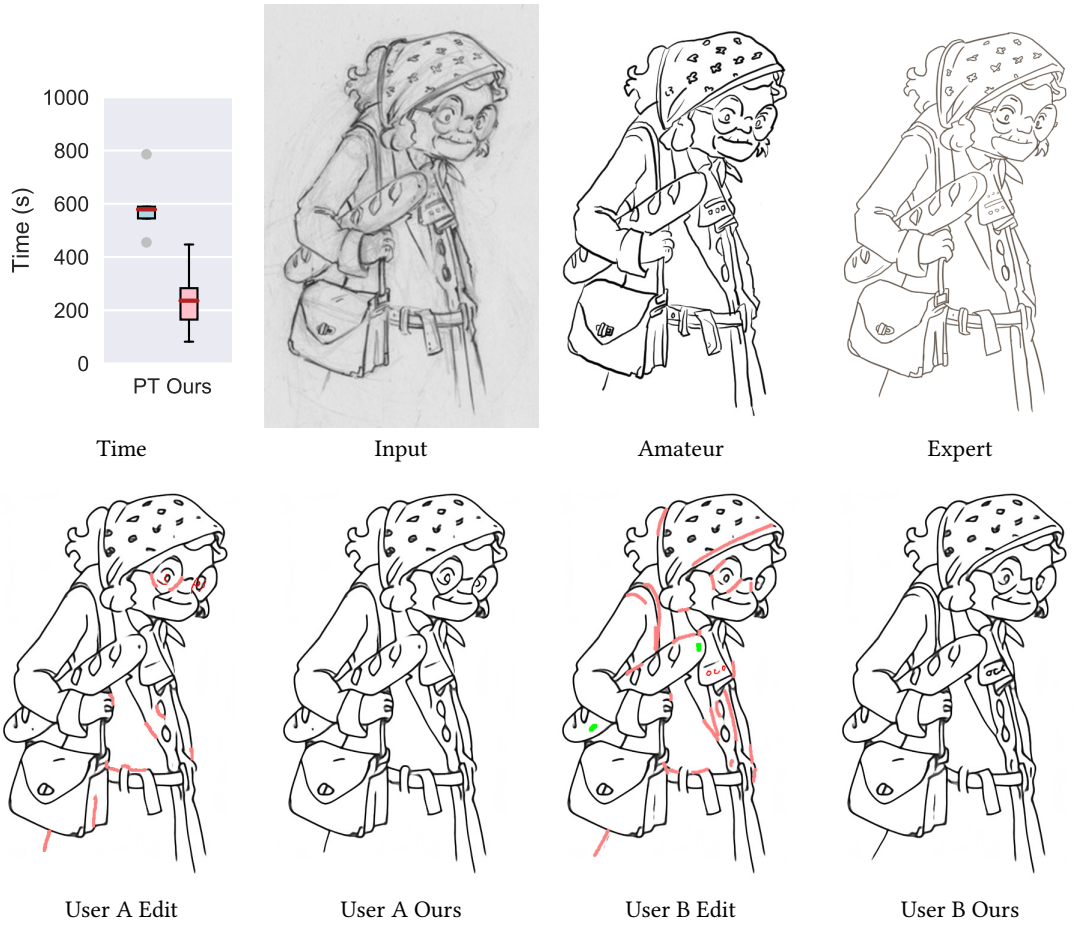


Fig. 3. Image 1 of the user study. We show an example inking result by an amateur and expert user using Clip Studio Paint Ex in the top row, and two examples done by users with our approach. Image is copyrighted by David Revoy (www.davidrevoy.com) and licensed under CC-by 4.0.

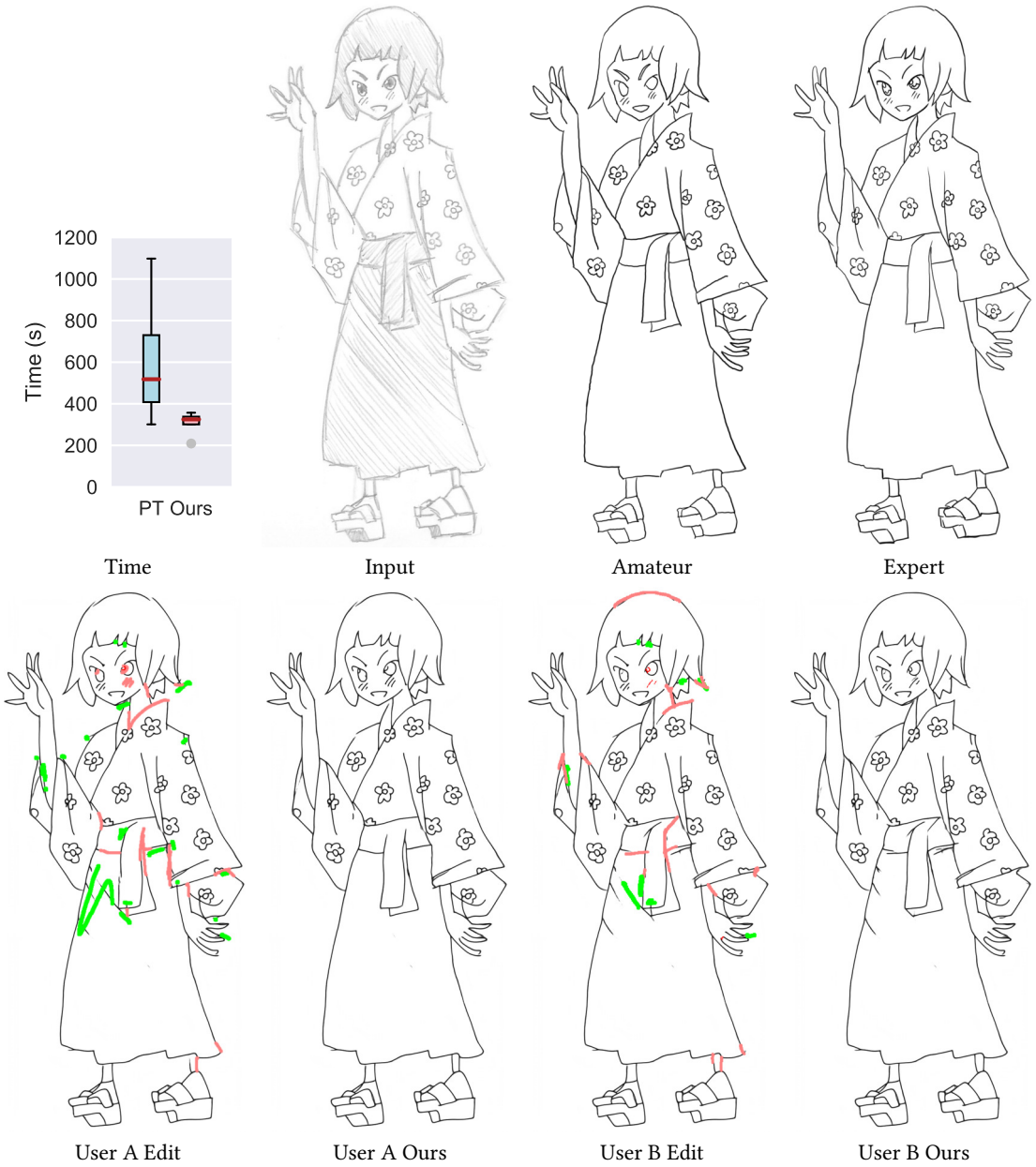


Fig. 4. Image 2 of the user study. We show an example inking result by an amateur and expert user using Clip Studio Paint Ex in the top row, and two examples done by users with our approach.

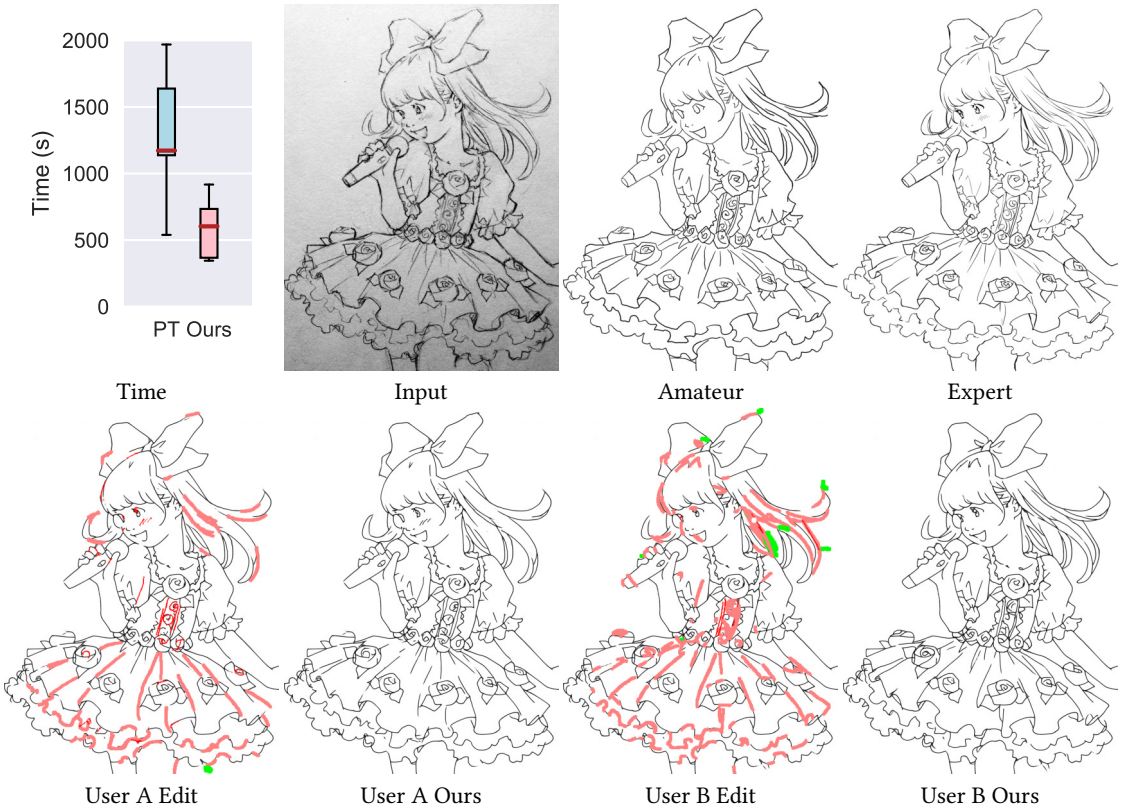


Fig. 5. Image 3 of the user study. We show an example inking result by an amateur and expert user using Clip Studio Paint Ex in the top row, and two examples done by users with our approach. Image is copyrighted by Eisaku Kubonouchi.

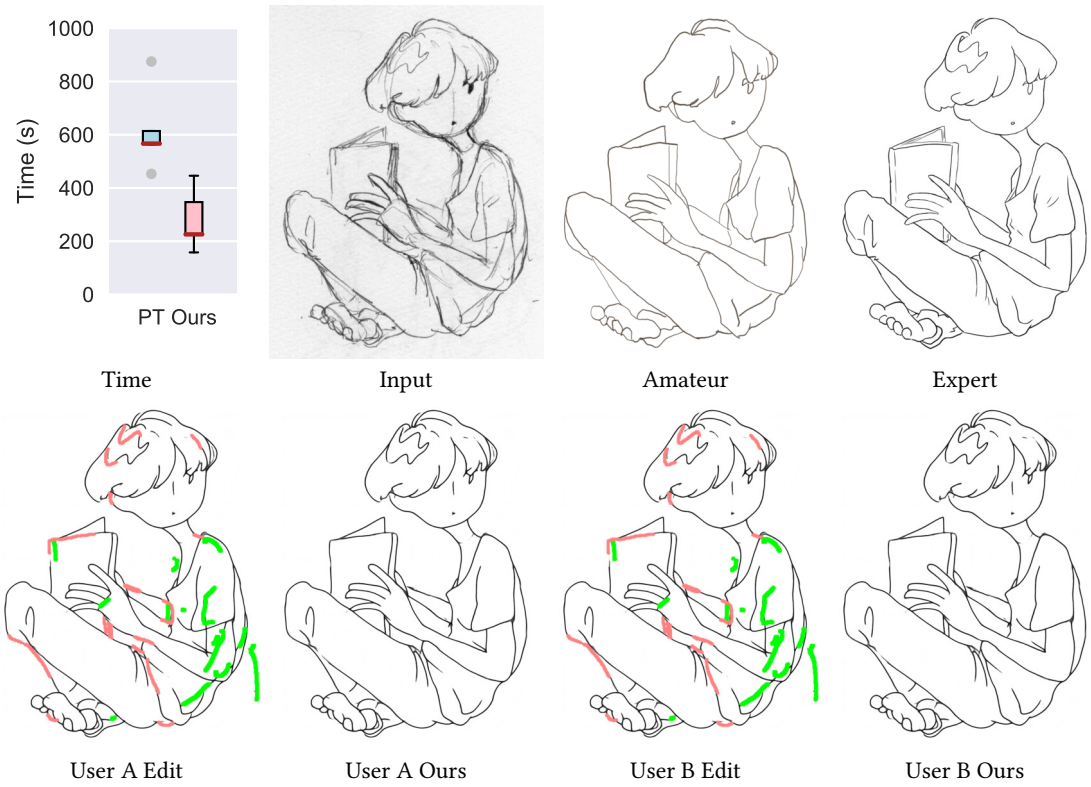


Fig. 6. Image 4 of the user study. We show an example inking result by an amateur and expert user using Clip Studio Paint Ex in the top row, and two examples done by users with our approach.

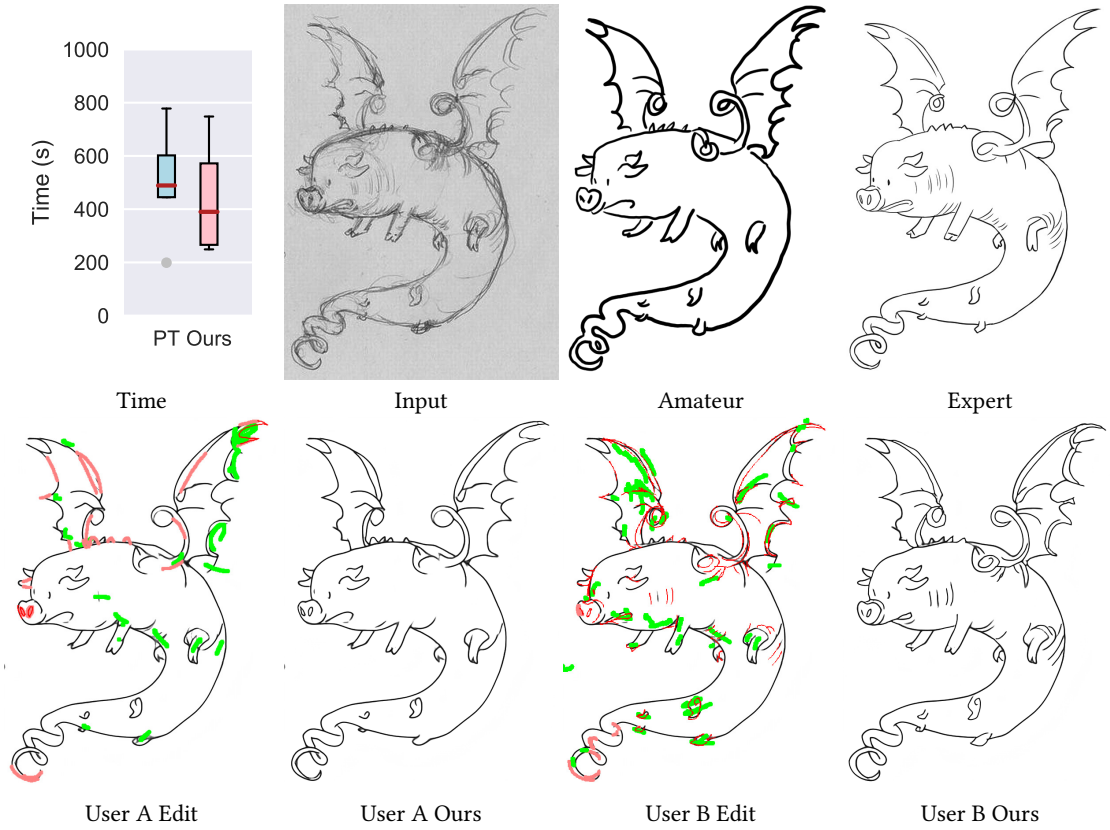


Fig. 7. Image 5 of the user study. We show an example inking result by an amateur and expert user using Clip Studio Paint Ex in the top row, and two examples done by users with our approach. Image is copyrighted by David Revoy (www.davidrevoy.com) and licensed under CC-by 4.0.

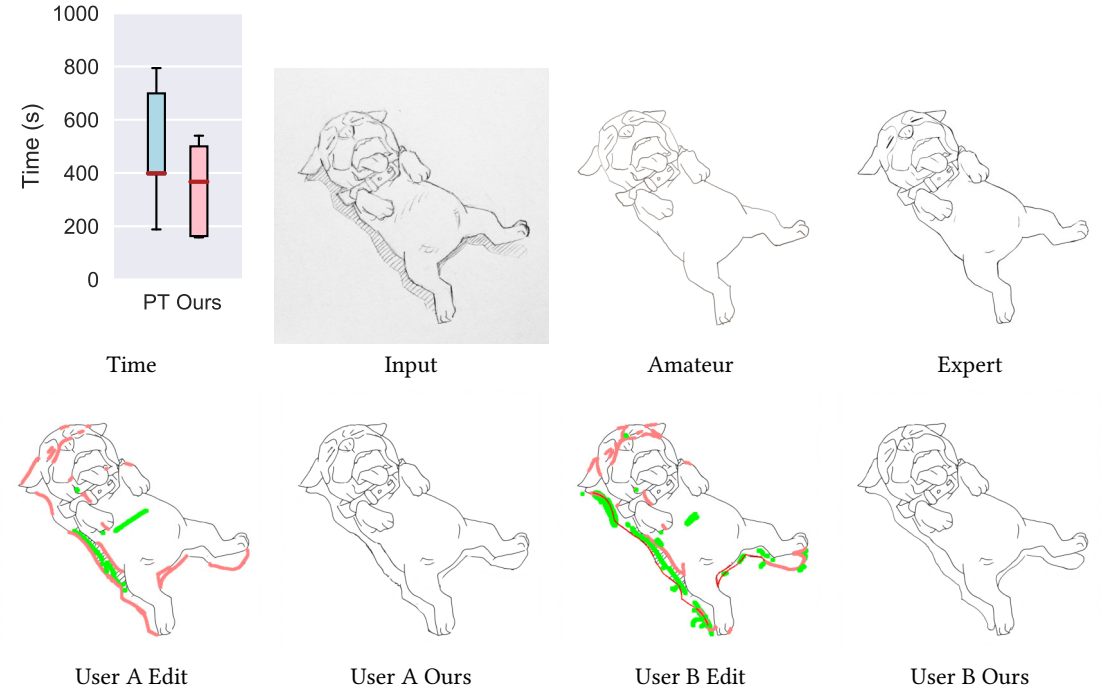


Fig. 8. Image 6 of the user study. We show an example inking result by an amateur and expert user using Clip Studio Paint Ex in the top row, and two examples done by users with our approach. Image is copyrighted by Eisaku Kubonouchi.

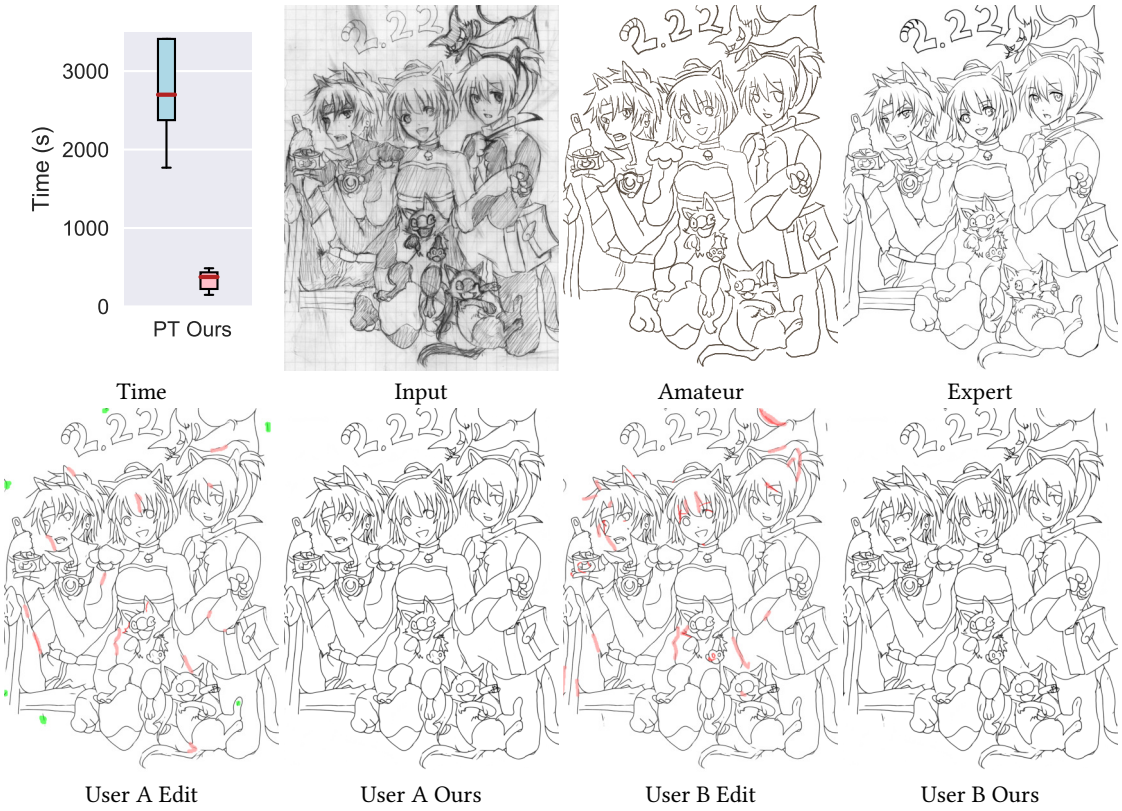


Fig. 9. Image 7 of the user study. We show an example inking result by an amateur and expert user using Clip Studio Paint Ex in the top row, and two examples done by users with our approach.

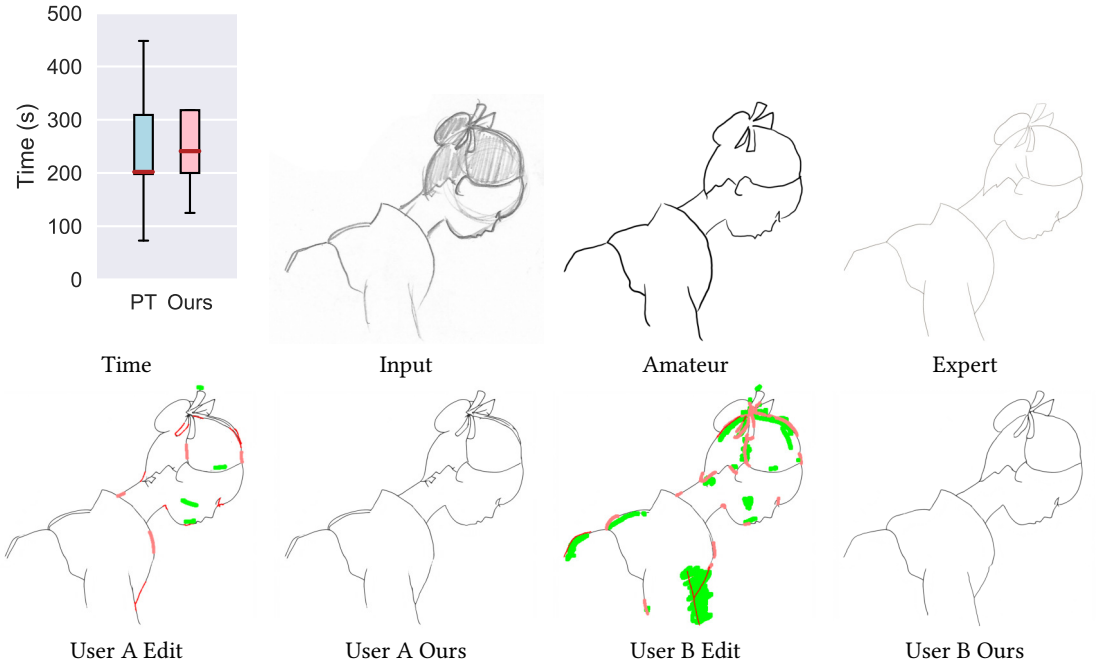


Fig. 10. Image 8 of the user study. We show an example inking result by an amateur and expert user using Clip Studio Paint Ex in the top row, and two examples done by users with our approach.

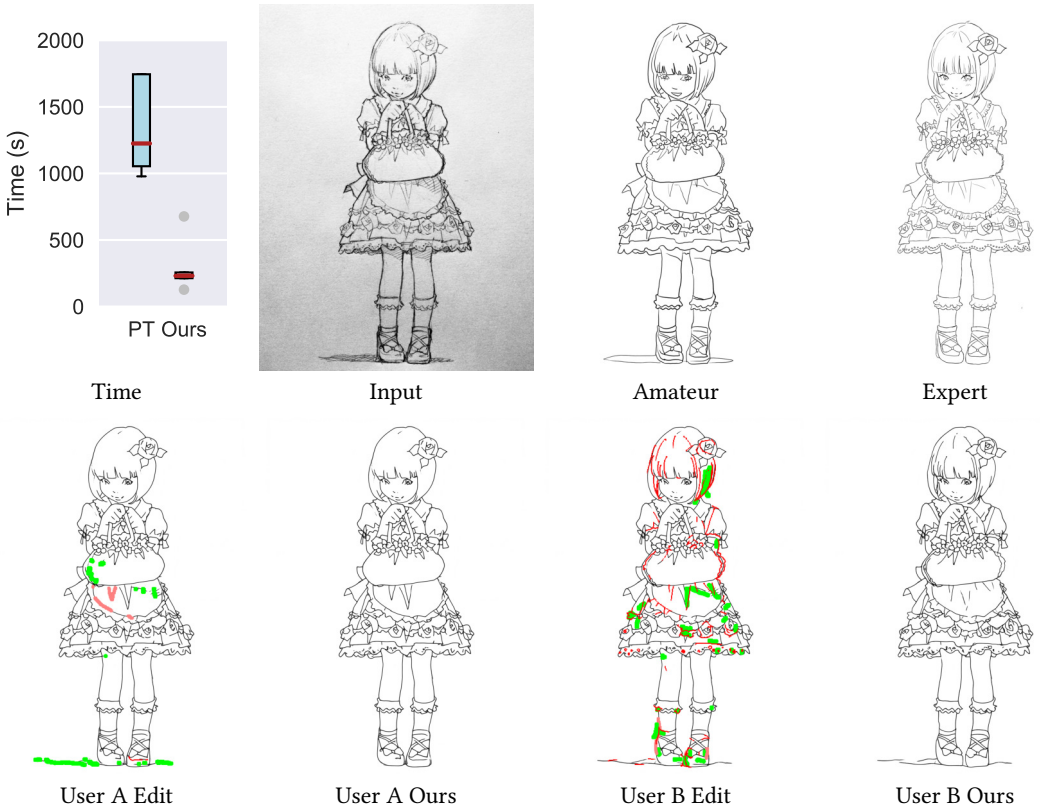


Fig. 11. Image 9 of the user study. We show an example inking result by an amateur and expert user using Clip Studio Paint Ex in the top row, and two examples done by users with our approach. Image is copyrighted by Eisaku Kubonouchi.

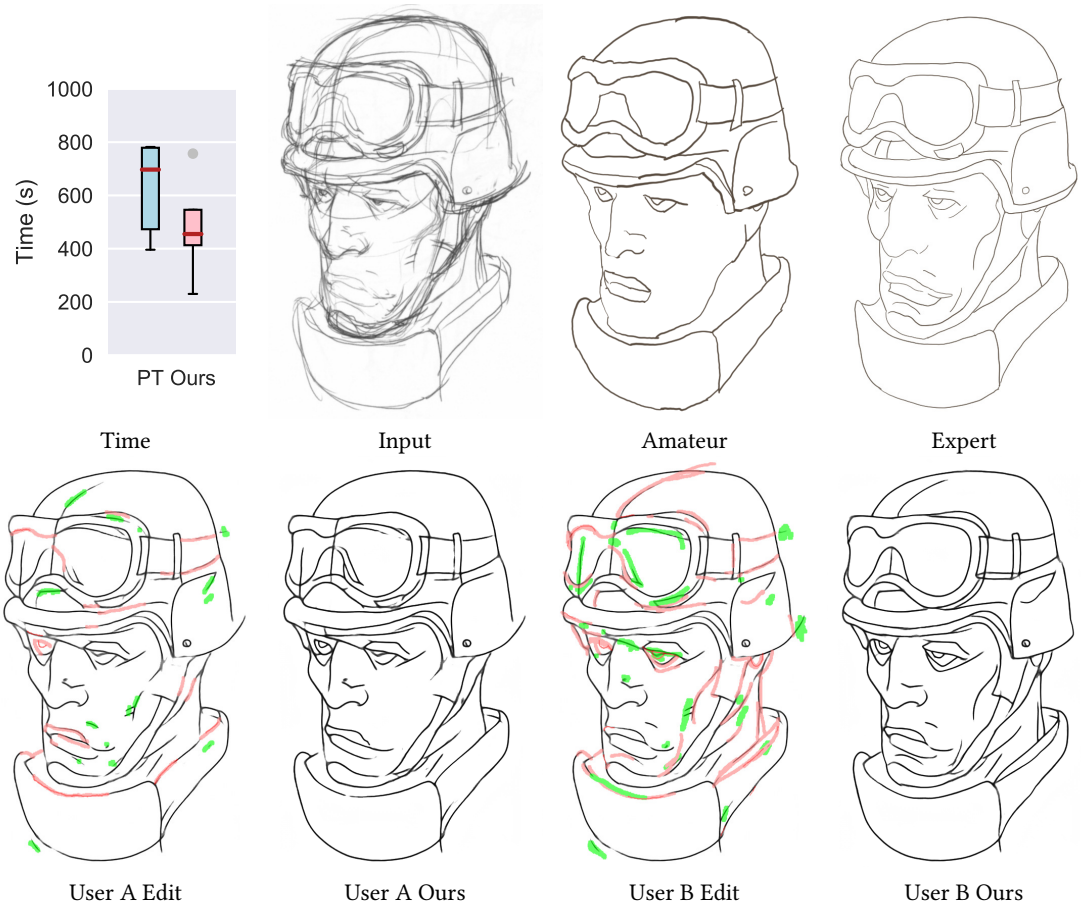
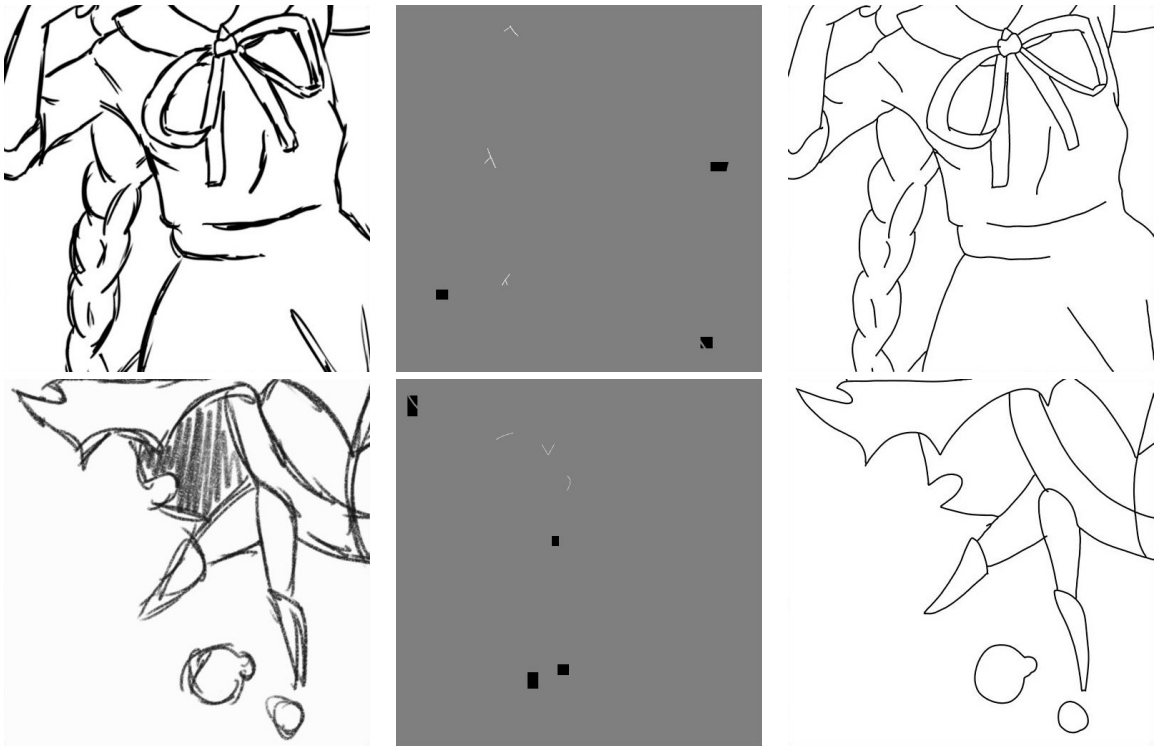


Fig. 12. Image 10 of the user study. We show an example inking result by an amateur and expert user using Clip Studio Paint Ex in the top row, and two examples done by users with our approach. Image is copyrighted by Krenz Cushart and is part of Krenz's Artwork Sketch Collection 2004-2013.



Rough Sketch Edit Map Ground Truth

Fig. 13. Example of training data used to train our baseline model. This data is generated by randomly using patches of the ground truth as "pen" or "eraser" inputs. The user edit shows the lines in white, eraser in black, and the gray values indicate no edit.

2 BASELINE APPROACH

We train a model following a similar approach to those of [2] and [5]. Their approach consists of training interactive colorization networks by providing color hints to the model during training. This color hints consist of patches or points of the ground truth. Given that it is not very practical to ink rough sketches using points, we opt for the patch approach. In particular, we randomly sample 10 to 30 pixel patches of the ground truth, and randomly show either the line information or the white space information to the model. Up to 8 patches are sampled per image, similar to how our approach can have up to 8 simulated user edits. An example of the data used to train the baseline model is shown in Fig. 13. This baseline approach is unable to properly learn to use the eraser tool, and in particular has a tendency to draw lines around erased areas as shown in Fig. 14. Our proposed user edit simulation avoids this problem entire, while also allowing us to use the inker brush tool, which is the most appreciated by the users as shown by our user test. It is not possible to train a inker brush tool using simple approaches based on showing only the ground truth to the model.

3 IMAGE GENERATION

While our approach focuses on inking images, it can also be used as a drawing tool, in which the inker pen and inker brush tools will help auto-complete and connect strokes. A simple illustration is shown in Fig. 15. In this example, the

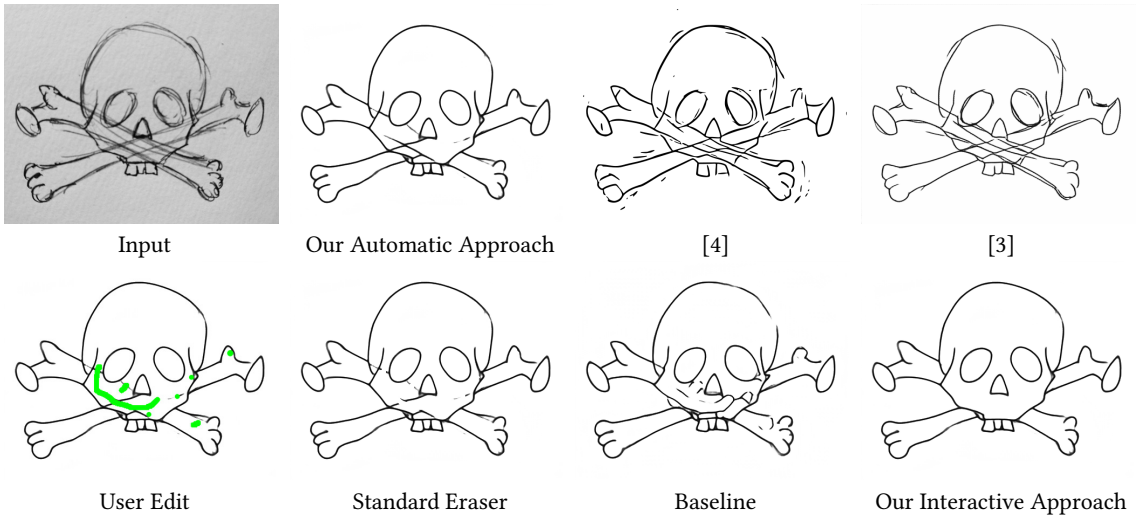


Fig. 14. Comparison of our approach with automatic and interactive approaches. The standard eraser is the result of using the standard eraser tool found in most software with the provided user edits. The baseline consists in a model in which parts of the ground truth are shown as user edits during training.

Fig. 15. Example of stroke continuity preserving by our approach. We input a completely white image as a rough sketch and show the effect of different additive edits. It is able to conserve the continuity of strokes in primitives as shown on the left and right, while still being able to distinguish between nearby parallel lines as shown in the middle. Furthermore, it is possible to seamlessly combine the inker pen tool and inker brush tool to create a single continuous line as shown below.

inputted rough sketch is white, containing no information. We provide some drawings as the user input, and see how our approach is able to complete curved lines, straight lines and crossings, while also avoiding joining parallel lines.

4 LINE NORMALIZATION

4.1 Models

We provide the full details of both the *wide* and *nimble* line normalization models in Tables 4 and 5, respectively.

Table 4. Overview of the line normalization *wide* model architecture. We specify layer irregularities in the notes column. When the same layer is repeated several times consecutively, we indicate this with the number of times in parenthesis.

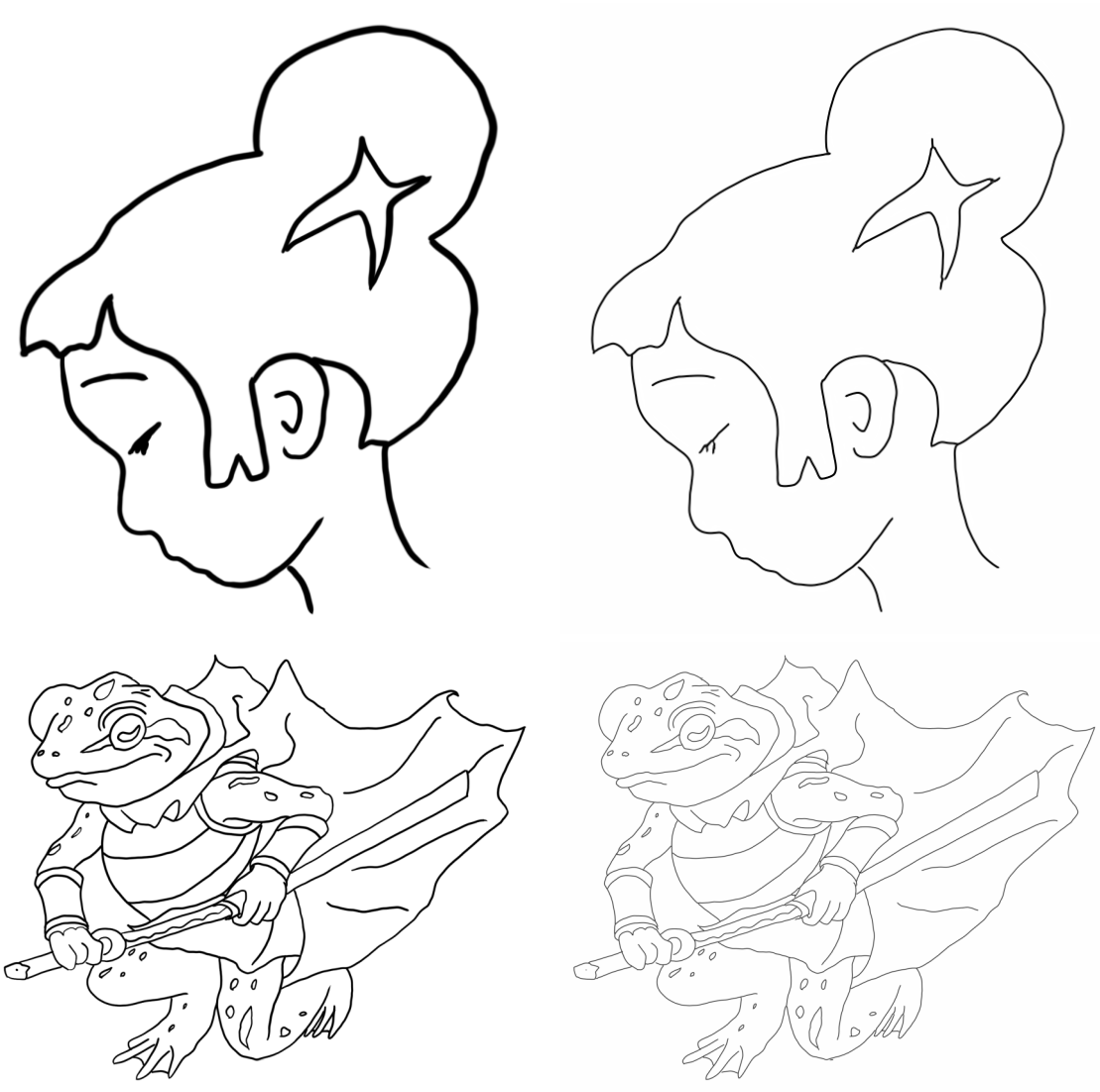
Layer Type	Output Resolution	Notes
Input	$1 \times W \times H$	Line drawing
Convolution	$64 \times W \times H$	9×9 kernel, reflection padding
Convolution ($\times 7$)	$64 \times W \times H$	
Convolution	$1 \times W \times H$	No batch normalization, sigmoid

Table 5. Overview of the line normalization *nimble* model architecture. We specify layer irregularities in the notes column. When the same layer is repeated several times consecutively, we indicate this with the number of times in parenthesis.

Layer Type	Output Resolution	Notes
Input	$1 \times W \times H$	Line drawing
Convolution	$32 \times W \times H$	9×9 kernel, reflection padding
Convolution ($\times 3$)	$32 \times W \times H$	
Convolution	$1 \times W \times H$	No batch normalization, sigmoid

4.2 Additional Results

We show some examples of full line drawings that have been normalized for use in training our model in Fig. 16. We can see how our approach is able to accurately normalize the thickness of all the lines and produce clean anti-aliased outputs.



Ground Truth Normalized

Fig. 16. Examples of normalized line drawings amenable for training.

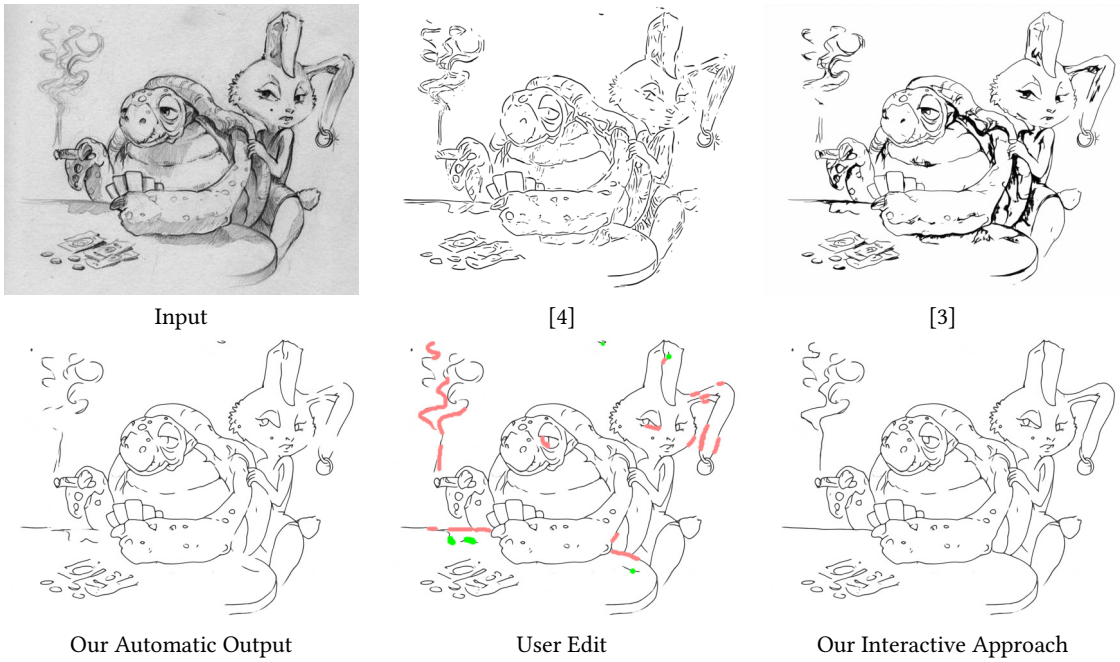


Fig. 17. Example result. Image is copyrighted by David Revoy (www.davidrevoy.com) and licensed under CC-by 4.0.

5 ADDITIONAL RESULTS

We present additional results and comparisons of our approach with existing approaches [3, 4]. The results of [4] are shown using the post-processing they proposed, while the results of [3] are shown without post-processing as they point out it is not necessary. For our approach, we show the automatic results and the results of the interactive user editing.

We can see that the approach of [4] tends to break down on complicated images. This is a result of blurry predictions in combination with the post-processing, which lead to low quality inking results. The approach of [3] tends to conserve more thinner lines, but breaks down with heavy texture or shading. Smart Inker already shows better automatic inking result, especially on challenging rough sketches, which can be complemented with the interactive user editing to achieve results that are amenable to colorizing without further processing of the line drawing.

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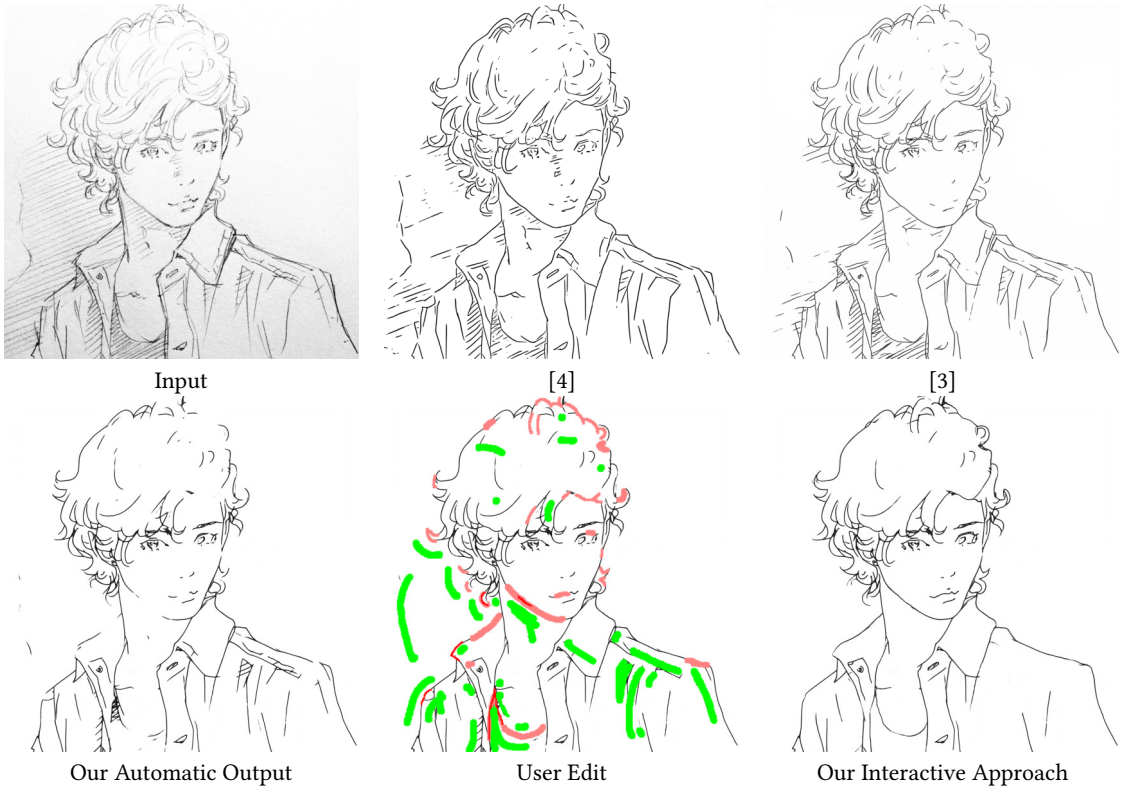


Fig. 18. Example result. Image is copyrighted by Eisaku Kubonouchi.

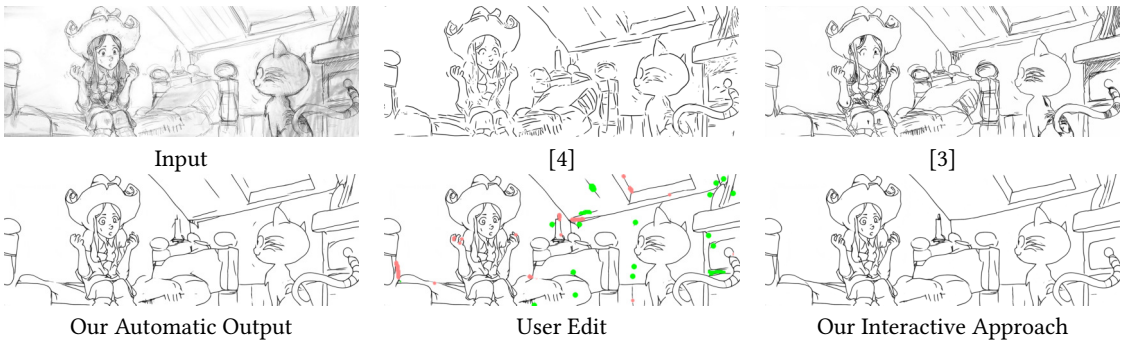


Fig. 19. Example result. Image is copyrighted by David Revoy (www.davidrevoy.com) and licensed under CC-by 4.0.

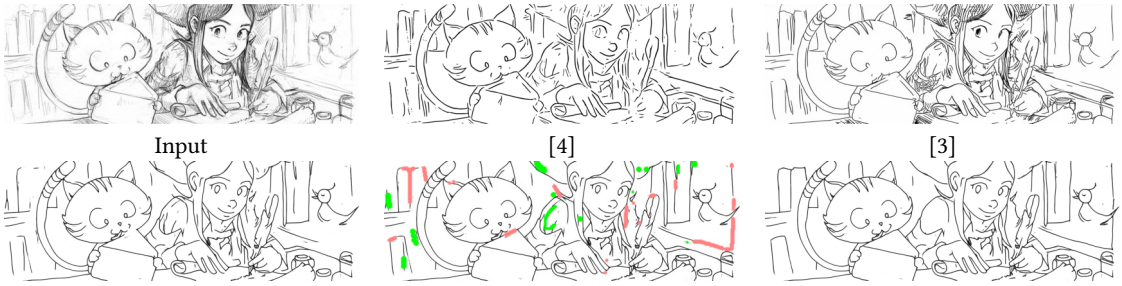


Fig. 20. Example result. Image is copyrighted by David Revoy (www.davidrevoy.com) and licensed under CC-by 4.0.

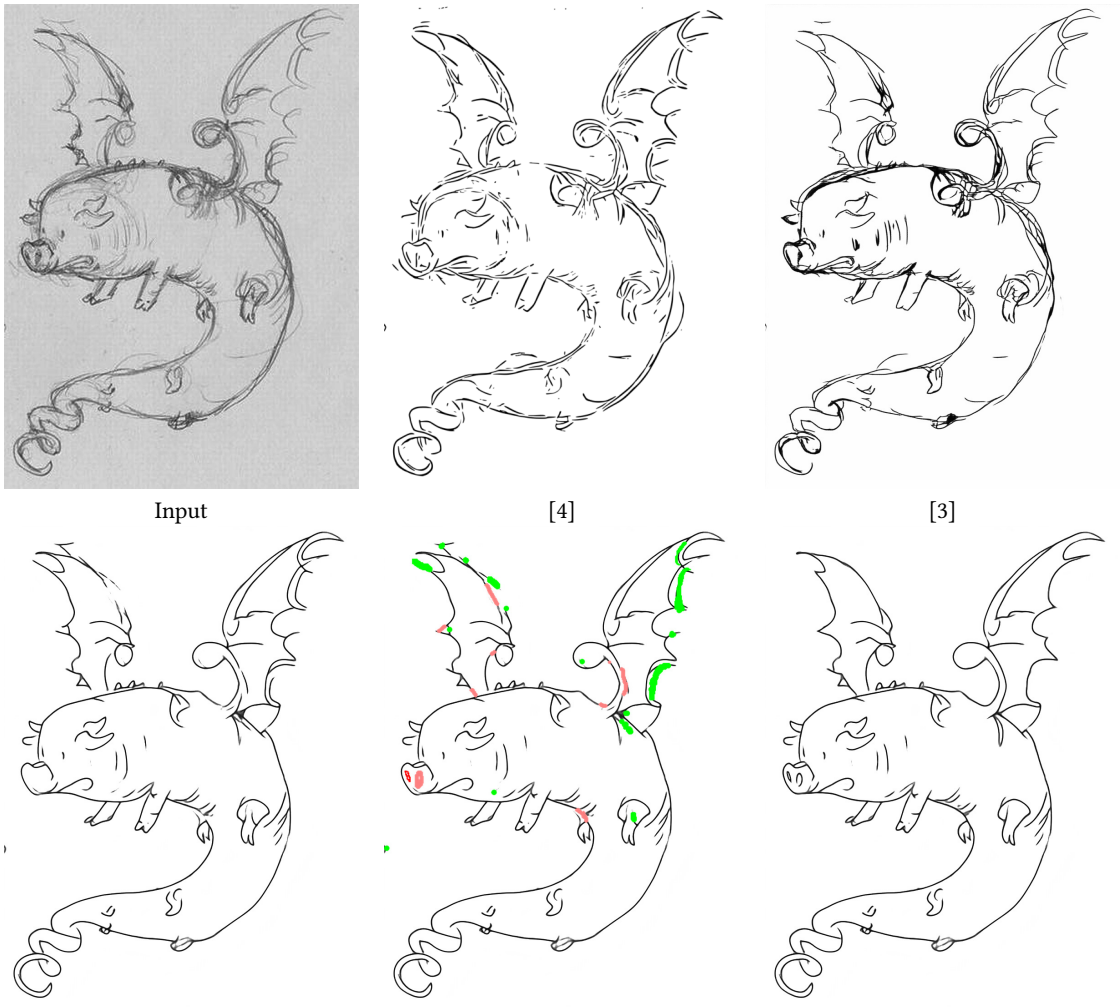


Fig. 21. Example result. Image is copyrighted by David Revoy (www.davidrevoy.com) and licensed under CC-by 4.0.

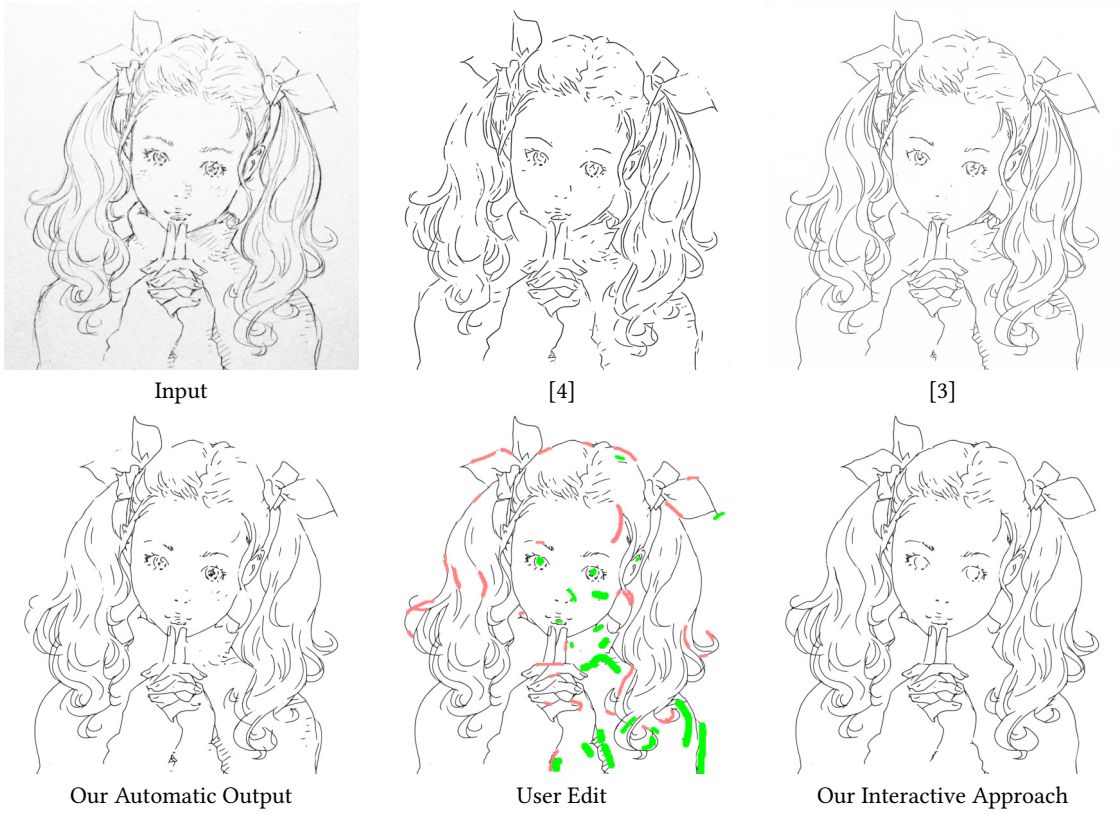
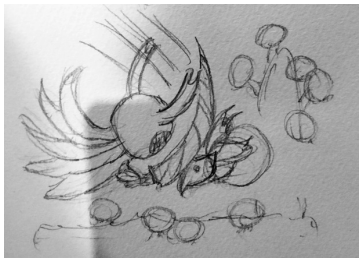


Fig. 22. Example result. Image is copyrighted by Eisaku Kubonouchi.



Input

[4]

[3]

Our Automatic Output

User Edit

Our Interactive Approach

Fig. 23. Example result.

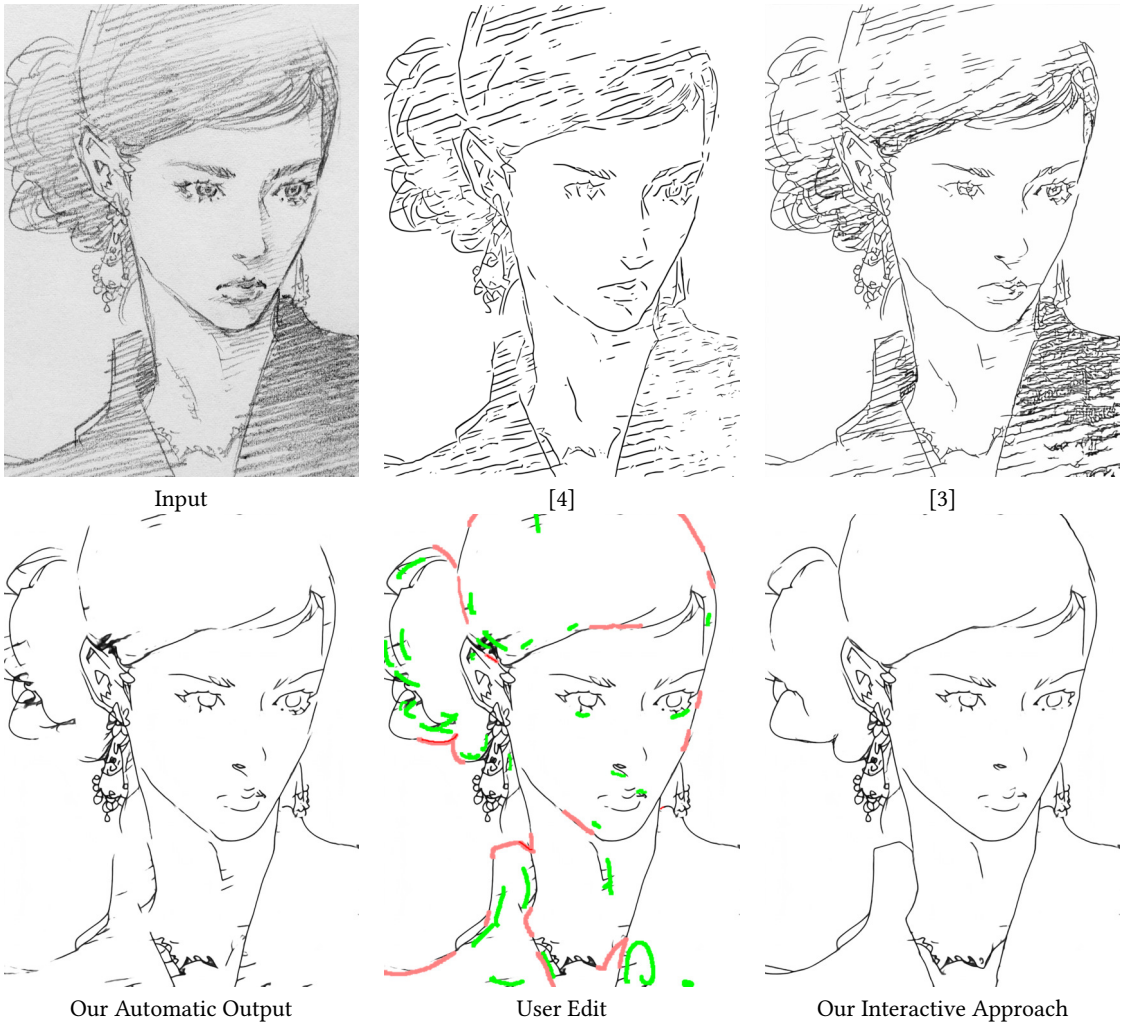


Fig. 24. Example result. Image is copyrighted by Eisaku Kubonouchi.

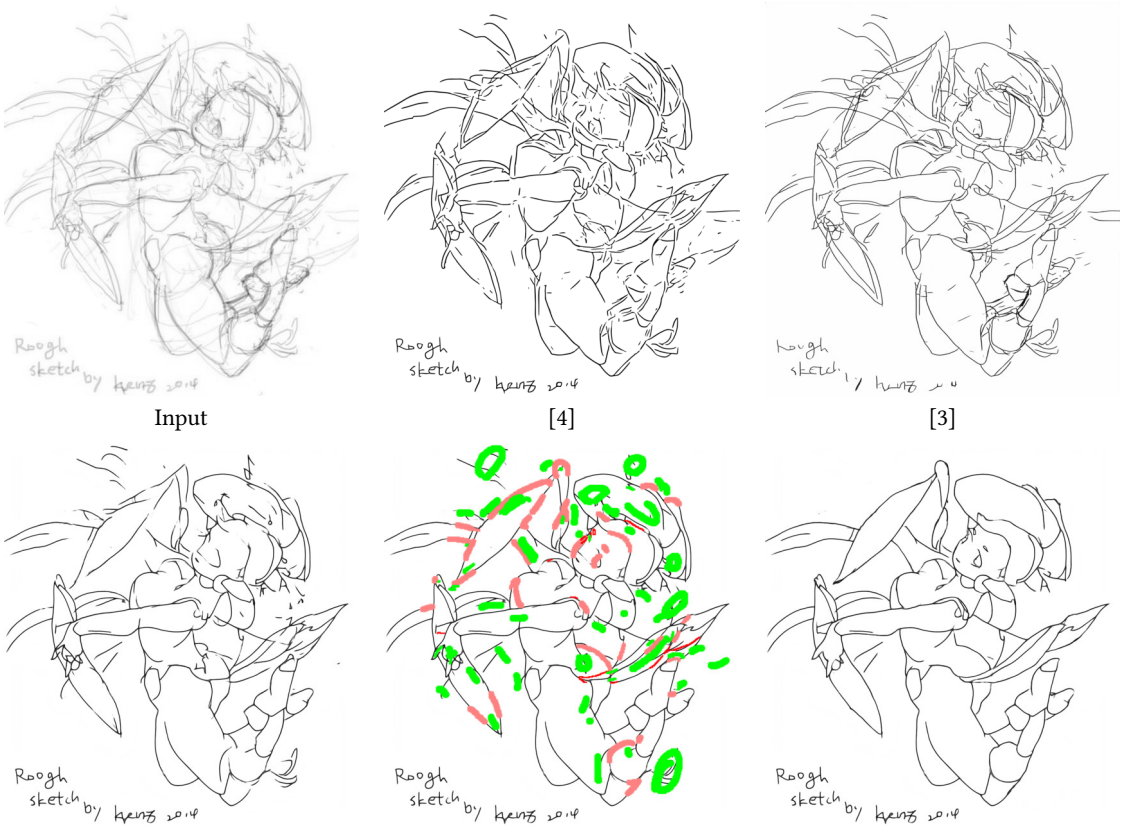


Fig. 25. Example result. Image is copyrighted by Krenz Cushart and is part of Krenz's Artwork Sketch Collection 2004-2013.

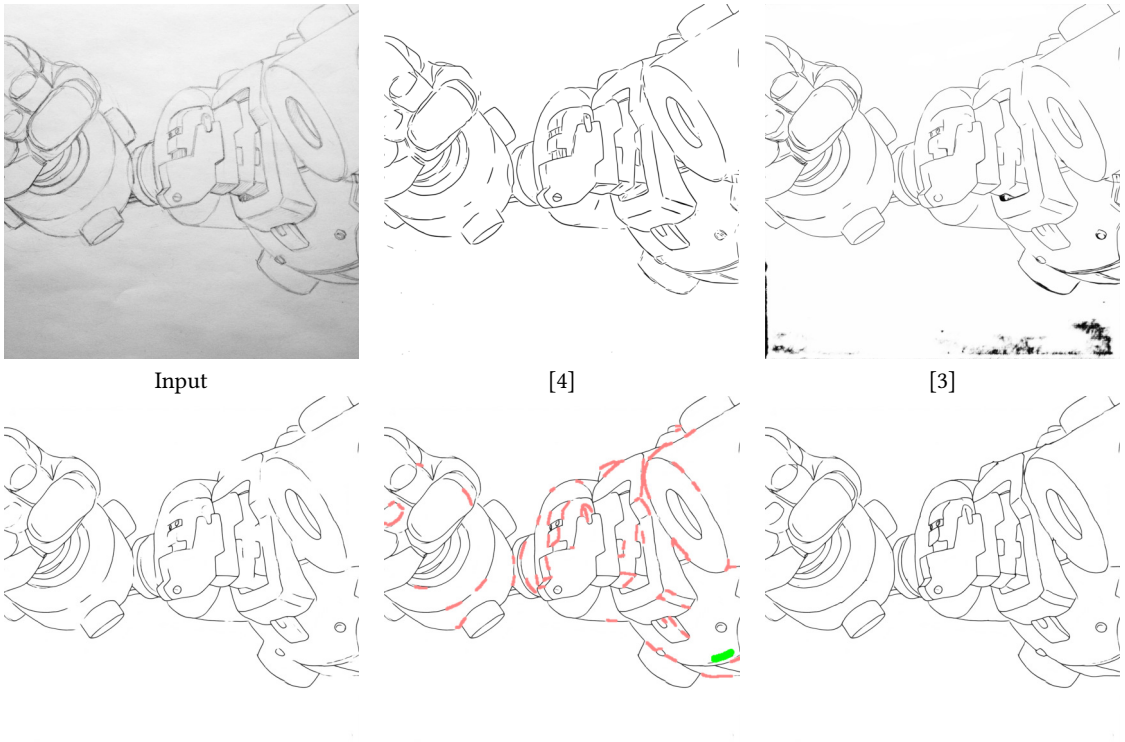


Fig. 26. Example result. Image is copyrighted by Eisaku Kubonouchi.

Fig. 27. Example result. Image by Vincent Van Gogh.

Input

[4]

[3]

Our Automatic Output

User Edit

Our Interactive Approach

Fig. 28. Example result.

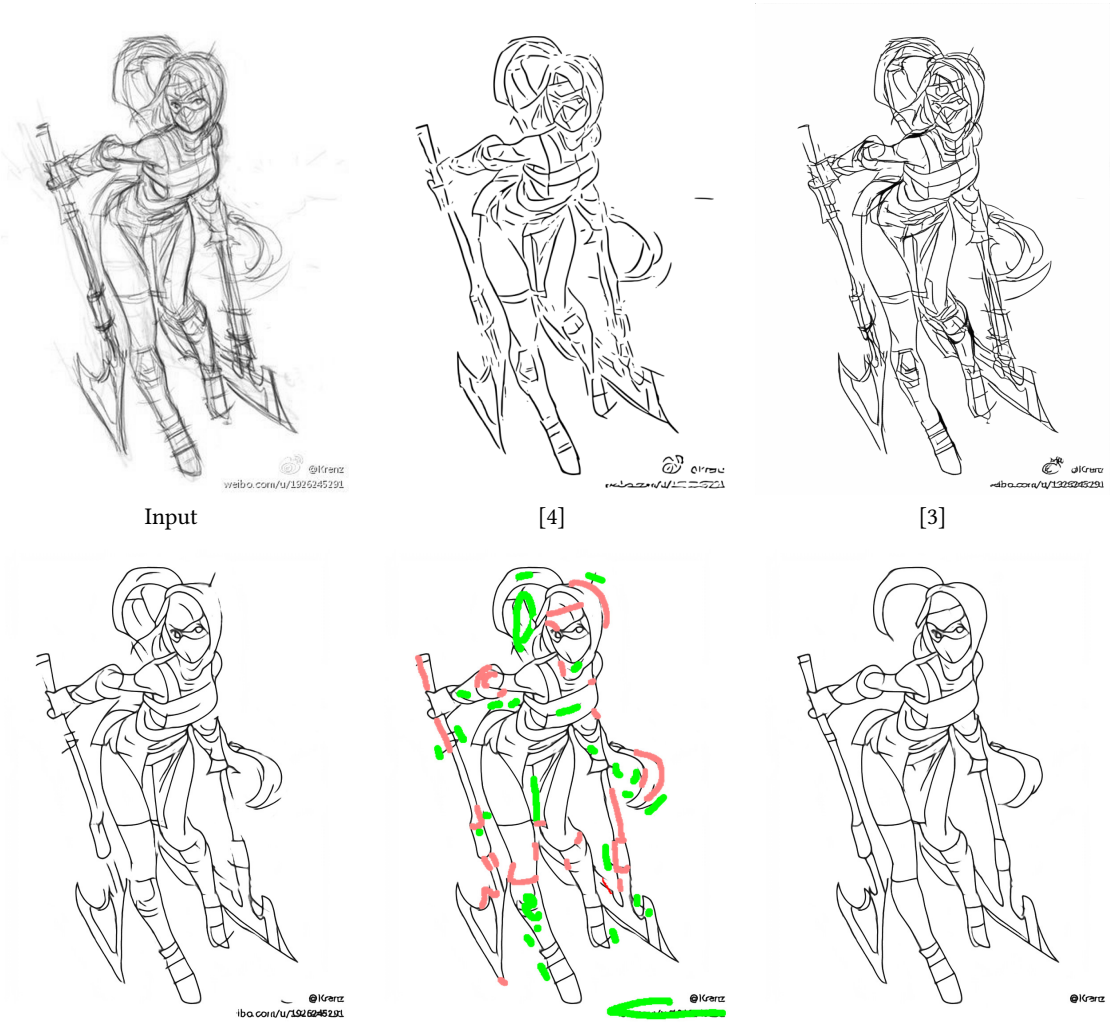
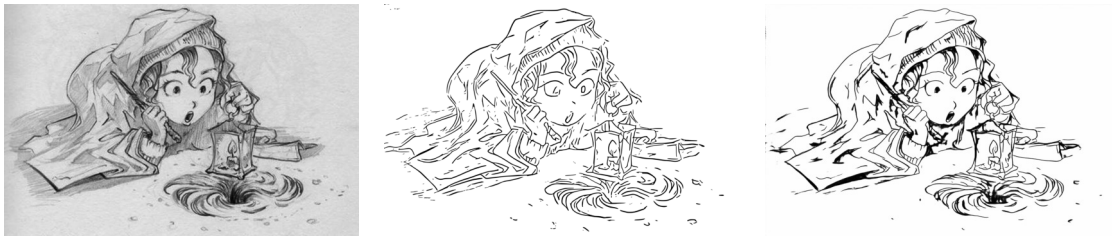


Fig. 29. Example result. Image is copyrighted by Krenz Cushart and is part of Krenz's Artwork Sketch Collection 2004-2013.



Input [4] [3]

Our Automatic Output User Edit Our Interactive Approach

Fig. 30. Example result. Image is copyrighted by David Revoy (www.davidrevoy.com) and licensed under CC-by 4.0.

Input [4] [3]

Our Automatic Output User Edit Our Interactive Approach

Fig. 31. Example result.

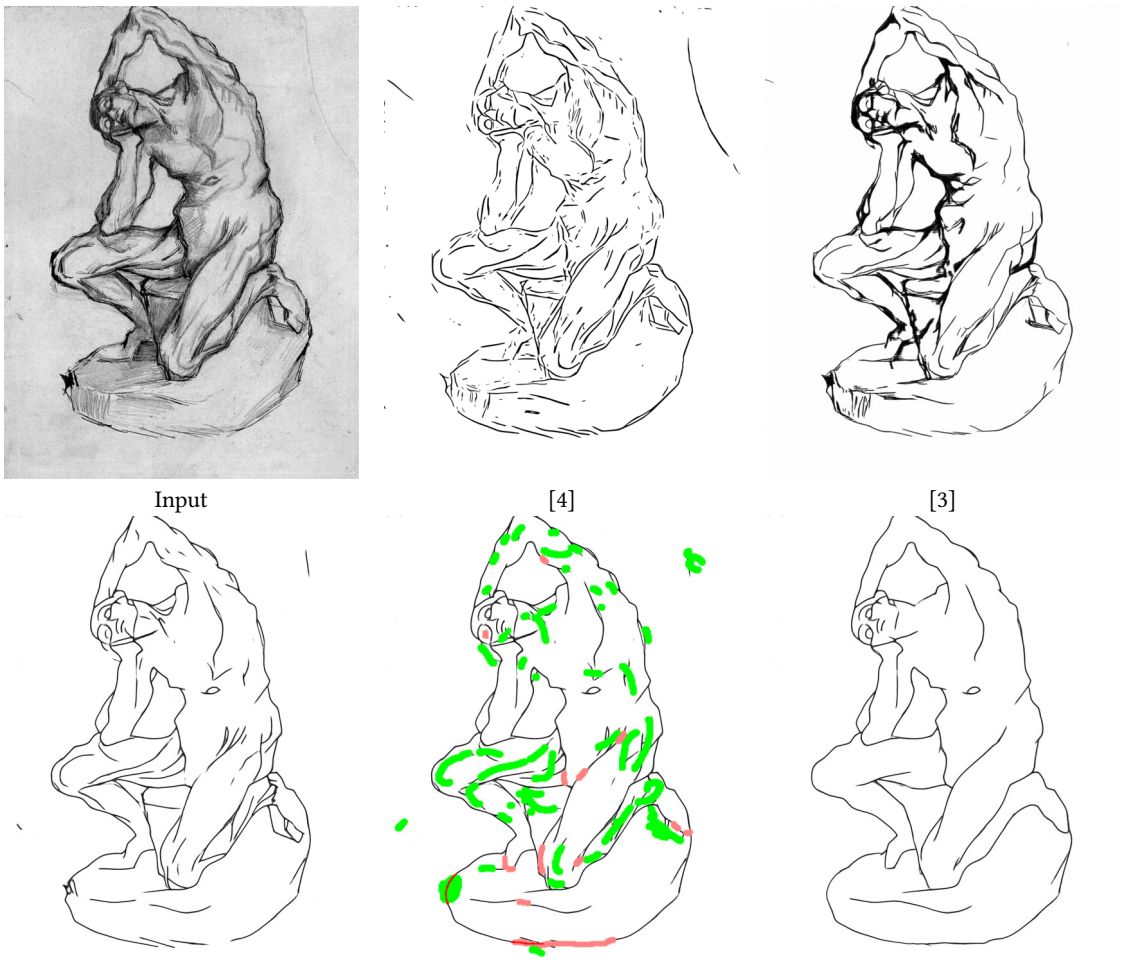
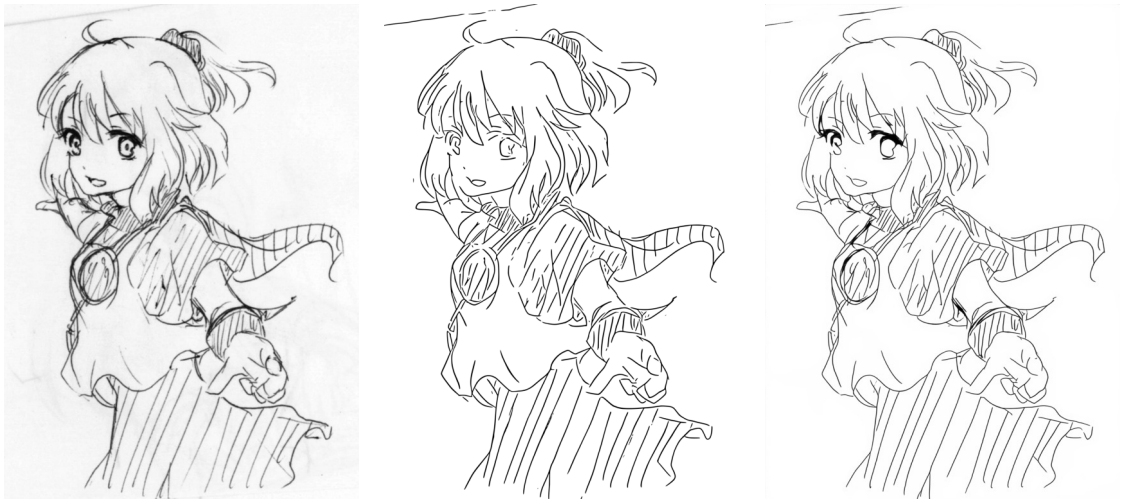


Fig. 32. Example result. Image by Vincent Van Gogh.



Input [4] [3]

Our Automatic Output User Edit Our Interactive Approach

Fig. 33. Example result.

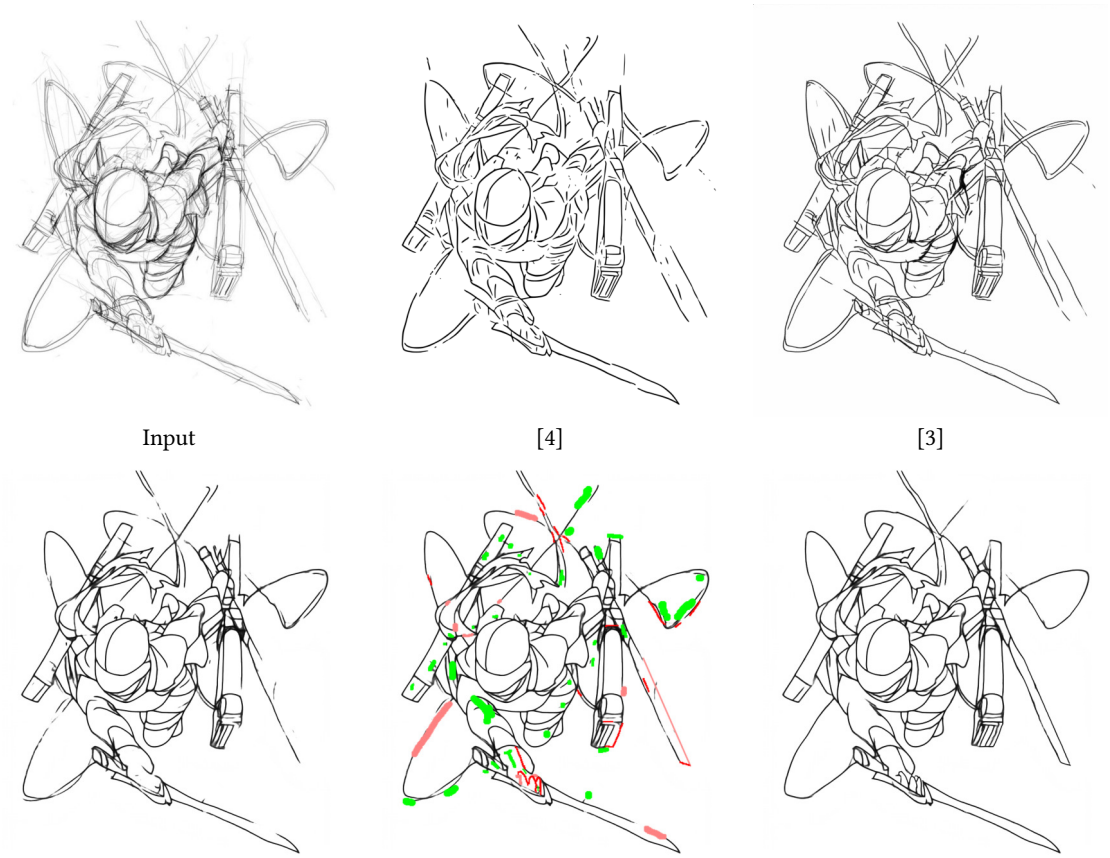


Fig. 34. Example result. Image is copyrighted by Krenz Cushart and is part of Krenz's Artwork Sketch Collection 2004-2013.

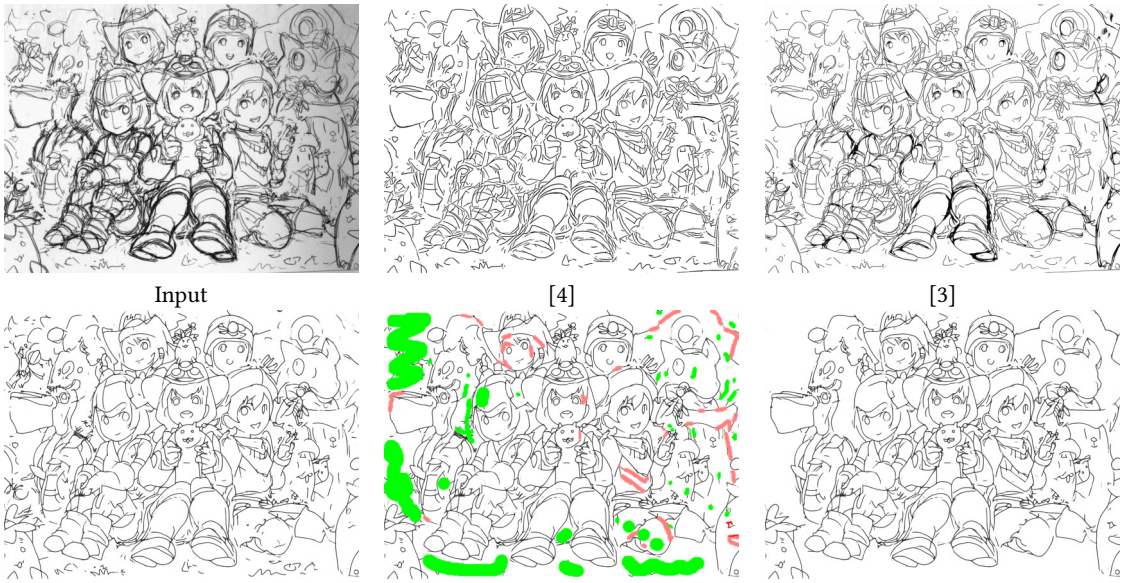


Fig. 35. Example result. Image is copyrighted by Krenz Cushart and is part of Krenz's Artwork Sketch Collection 2004-2013.

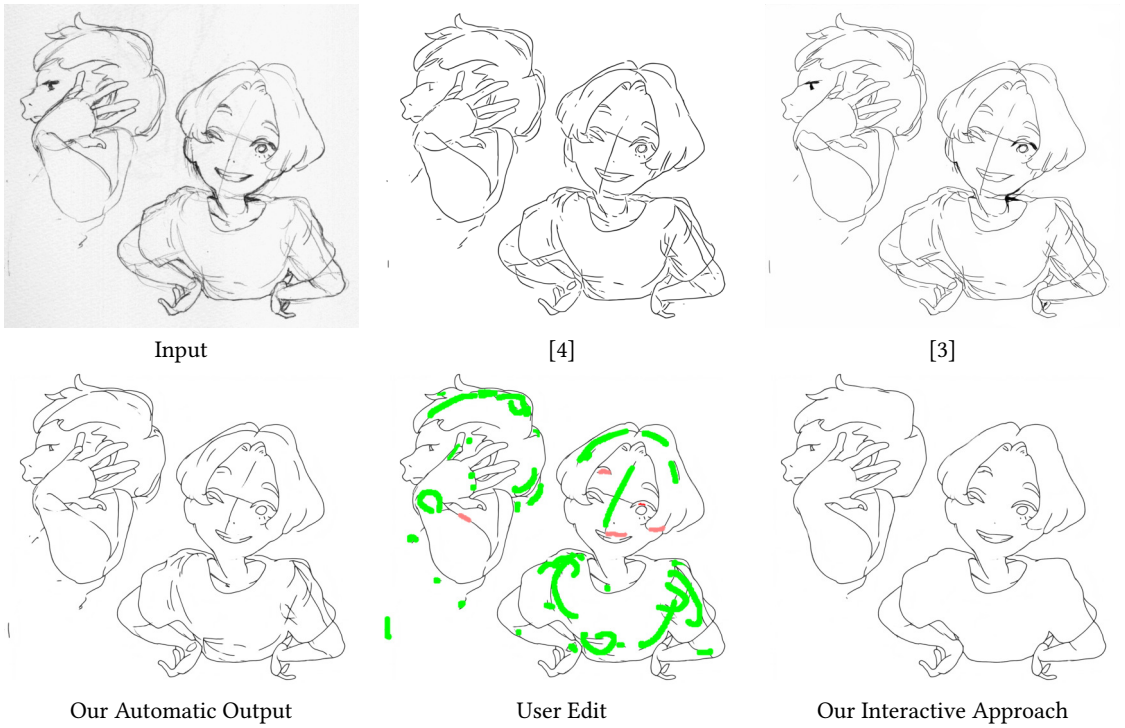


Fig. 36. Example result.

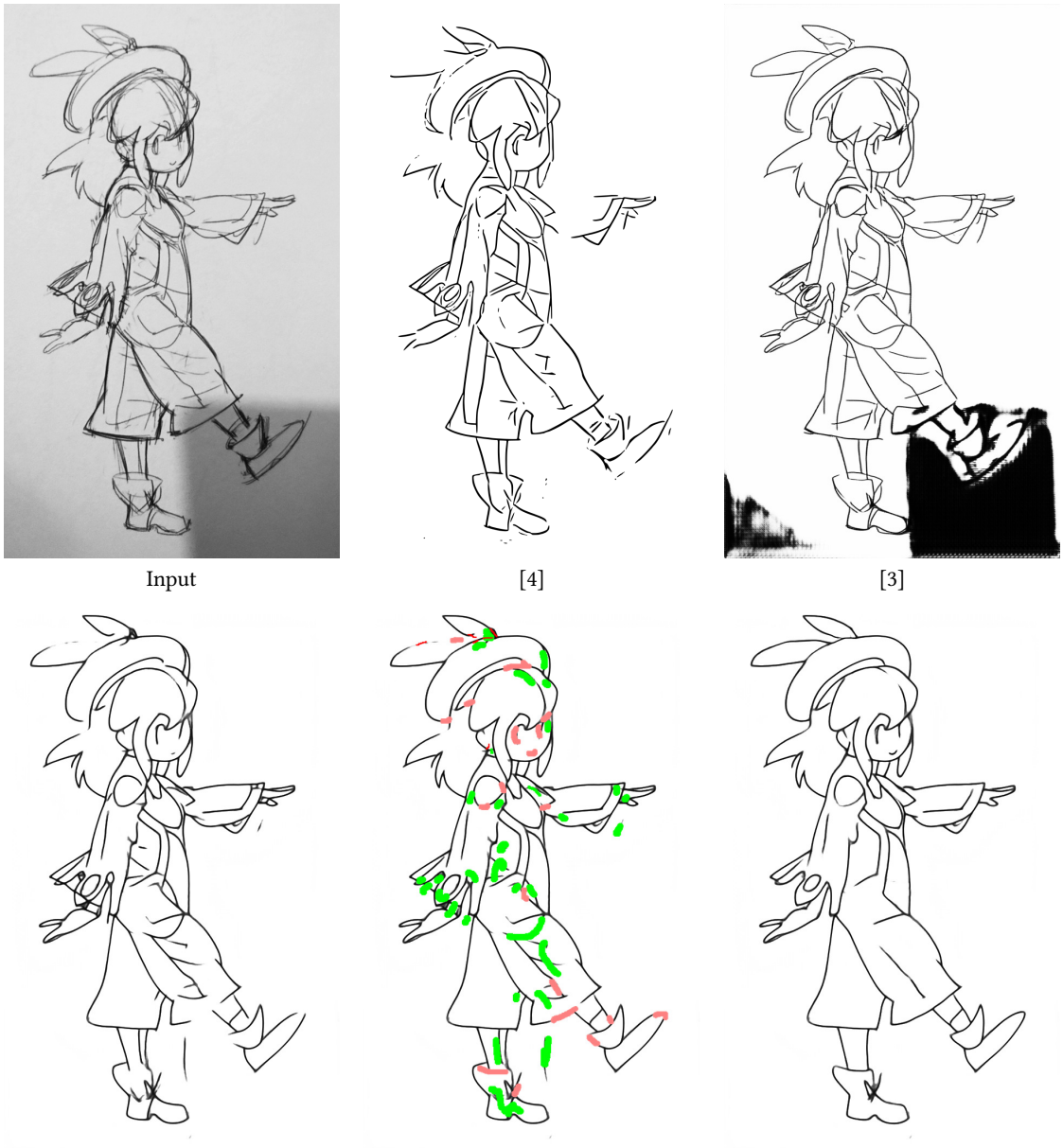


Fig. 37. Example result. Image is copyrighted by Krenz Cushart and is part of Krenz's Artwork Sketch Collection 2004-2013.

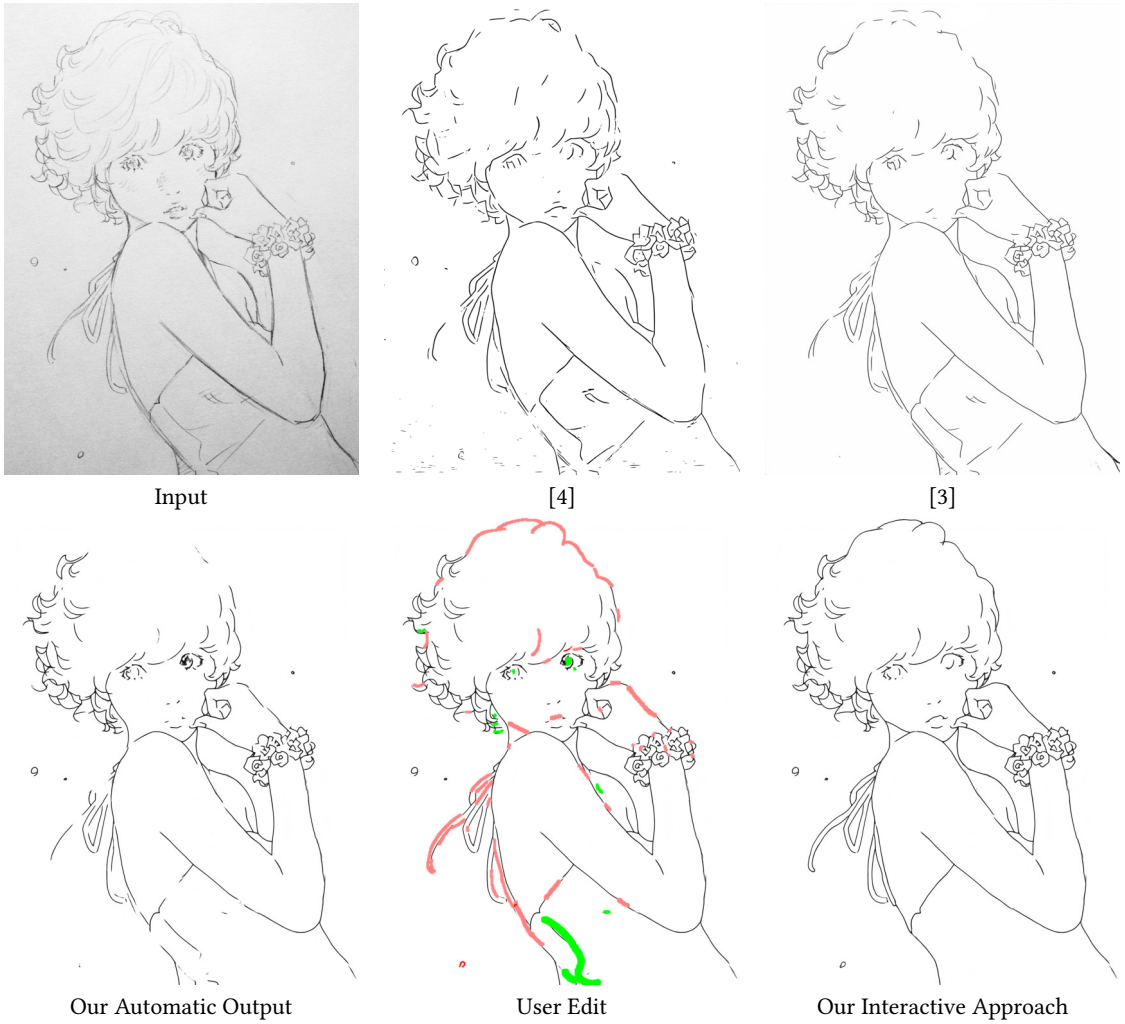


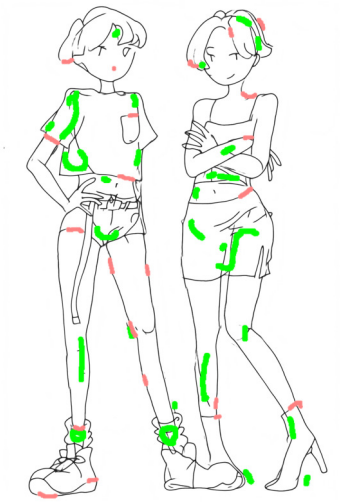
Fig. 38. Example result. Image is copyrighted by Eisaku Kubonouchi.

Input

[4]

[3]

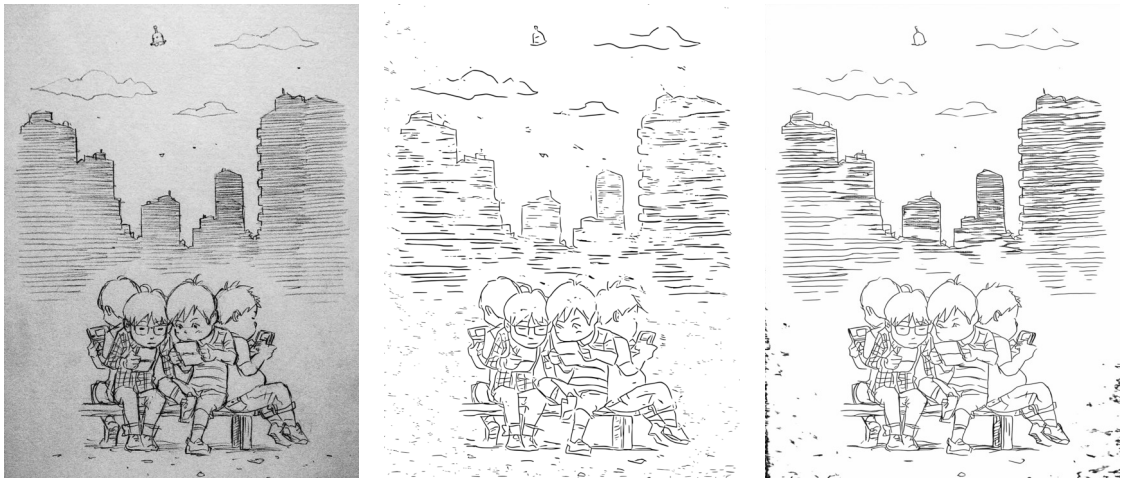
Our Automatic Output



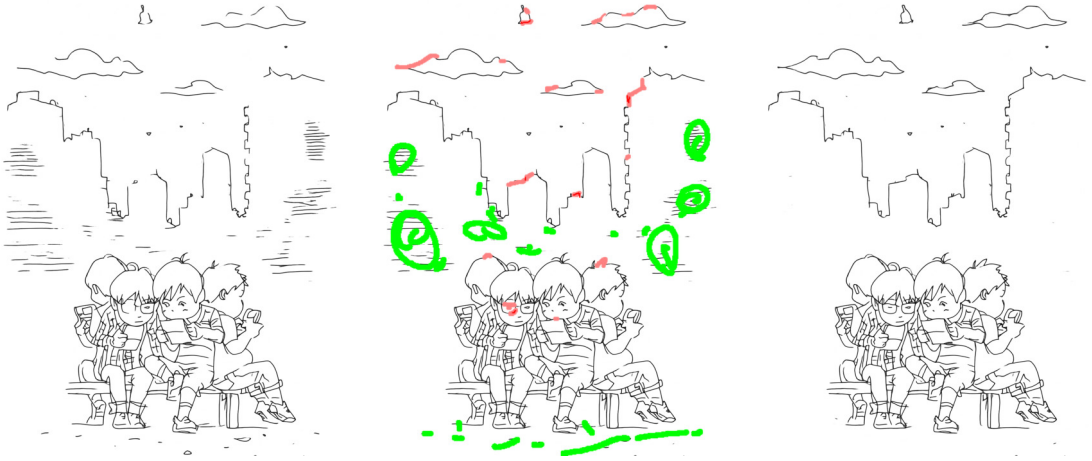
User Edit

Our Interactive Approach

Fig. 39. Example result.



Input [4] [3]



Our Automatic Output User Edit Our Interactive Approach

Fig. 40. Example result. Image is copyrighted by Eisaku Kubonouchi.