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Sketches by Paul the Robot

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Abstract

In this paper we describe Paul, a robotic installation that produces observational sketches of people. The sketches produced have been considered of interest by fine art professionals in recent art fairs and exhibitions, as well as by the public at large. We identify factors that may account for the perceived qualities of the produced sketches. A technical overview of the system is also presented.

Categories and Subject Descriptors (according to ACM CCS): I.3.3 [Computer Graphics]: Picture/Image Generation—Visual Arts

1. Introduction

The act of producing drawings from observation is a process that still exercises fascination. It is also considered to be a difficult skill to acquire that only the gifted can master. Paul is a robotic art installation developed by and based upon the style of artist-scientist Patrick Tresset, working in collaboration with Frederic Fol Leymarie. Paul produces observational drawings of people who pose in front of it using technologies and ideas developed in the context of the AIkon-II project at Goldsmiths, University of London, where we investigate the drawing activity through computational modelling and robotics with a focus on sketching faces from life. Although there are constant exchanges and overlaps between Patrick's art practice and the AIkon-II project, the aims are distinct; the former aims to produce installations to be considered in an artistic context, whilst the later is an investigation to be considered in a scientific context.

Drawings we are aiming to produce with an embodied sketching system such as Paul remain differentiable from those made by a human hand, and yet they have an emotional, aesthetic artistic effect on the observer that is comparable to that produced by drawings traced by human artists. We envisage that descendants of Paul that will benefit from the AIkon-II project's progress will draw in manners similar to that of humans, but with styles highly dependent and shaped by the system's physical and computational characteristics and limitations.

Paul was exhibited for the first time in June 2011 at the Tenderpixel Gallery in London, UK. Since then, Paul has drawn more than 700 members of the public, and sold more than 150 sketches. Paul has been exhibited in: the UK, the USA, Turkey, Italy. A portrait by Paul is now part of London's Victoria and Albert Museum's collection. The various contexts in which Paul has been exhibited include: (i) traditional visual art at the Thinking Through Drawing Symposium (NY, 2011) and The London Art Fair (2012), (ii) digital art at ISEA (Istanbul, 2011) and the Kinetica Art Fair (London, 2012), as well as for (iii) the general public (Victoria & Albert Museum), all of which have provided us with an extended range of feedback, comments and appreciations. Perhaps the highest impact comes from the professional art scene, including curators, critics, collectors and artists, especially drawing practitioners. From our experience a large proportion of this specialised audience accepts and evaluates Paul's production as being "surprisingly good" and interesting.

In this communication we will first survey contexts in which Paul fits. Then, after discussing factors that may account for the perceived qualities of the produced artworks, we will present a brief technical description.

2. Background

Since the beginning of the twentieth century *mechanical machines* have entered the art world as subjects, objects, metaphors or evocations such as in the work of Picabia, Duchamps, Ernst and others; yet, perhaps since Tinguely's inventions, other types of machines are present in the artistic

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Figure 1: *Paul sketching Stella at Tenderpixel Gallery, London, 2011*

Figure 2: *Stella by Paul, 2011, (cropped view).*

landscape [Rei87]. They exist more for what they do, how they act and interact rather than as objects to be depicted.

Today most research in robotics is geared towards creating utilitarian slave robots, such as those used in the manufacturing industry since the seventies. Such robots may act in a relatively near future as soldiers, cleaners, builders, drivers and a surgeon's assistant. In contrast robots invented by artists are anything but utilitarian, and they are even left free most of the time.

Since the birth of the Senster [GB10, Kac97], the sensual robotic creature created by Ed Inahtowicz [Ziv05] and exhibited in the early 1970's, a significant population of robotic entities have entered the art world. This population is more akin to a zoo, a "*court des miracles*", a theater, rather than a population of slaves, with such examples as *Le Petit mal* by Simon Penny [Kac97], *Sexed machines* by Paul Granjon [Gra08], *RoboCoco's* voyeur robots driven by curiosity [GS11], the *Robotic Action Painter* of Leonel Moura [Mou07], or *Kismet* the social robot by Cynthia Breazeal [Bre02]. Each of these specimens stays well clear of the "uncanny valley" [Mas70, Mac05]. Yet due to their movements, interactions, reactions, the human audience tends to express empathy and responds to these simple creatures as if they were alive.

Where does Paul stand in this context? Paul is not totally autonomous. It needs a human slave/assistant to perform the unskilled work: changing the paper. It is somewhat amusing that Paul gets invited to events where it performs and its creators just follow as human assistants. Paul is an obsessive drawing entity and alike most of its contemporary robotic

artworks it too stays far from the uncanny valley (*fig.*1). But Paul produces objects and as its utilitarian slave siblings, it can replace with more or less success the human, this time in a particular creative activity, that of drawing faces.

There are many examples of computerized systems attempting to draw from *reality* including portraits, *e.g.*, in computer graphics, within a sub-field referred to as Non-Photorealistic Rendering or NPR [GG01,Bre82,C*04]. Such systems produce approximate renderings extrapolated from reality, usually by taking digital images or 3D models as input. The majority of NPR systems are designed to render drawings or paintings in a particular style by producing output images mimicking a *final* result with relatively less attention paid to the creative steps involved in the artistic generation itself: *i.e.* how, as Zeki formulates it [Zek98], the artist extracts permanent, lasting and enduring features from a visual stimulus forming a novel presentation of the original subject. The pioneering work of Harold Cohen with his AARON system [Coh88] is probably the most well known example in which a *model of the artist's activity* whilst drawing/painting from *imagination* has been studied, implemented and refined over the years and successive generations of the system itself. An important difference with AARON is that Paul is conceived to produce drawings based on visual perception while AARON does not consider visual inputs.

3. Evaluation

Paul can be evaluated from two different perspectives: *i)* as an interactive robotic installation, and *ii)* as a system that generates drawings. In this paper we will focus on evaluating Paul's production. From the experience of exhibiting Paul's drawings to a wide audience we have noticed that one of the interesting properties of the sketches produced is that they are perceived, considered and appreciated as drawings. When observing a series of Paul drawings they appear obviously drawn by the same author as they display an autographic style.There is little doubt about their non-human authorship, especially when observing at close range details of Paul's sketches. However, contrary to other computational system that produces drawings from photographs such as AIkon-I [TFL06], drawings produced by Paul do not display the same serial uniformity of treatment (see *fig.*3).

Drawing surface as an object An artwork is an object that has to be perceived as rare, collectible and of high quality. The paper used by Paul has been chosen with great care to add to the feeling of quality, and to bring the appearance closer to a traditional drawing. To distance the sketches general appearance from a printed, computer generated artifact, the paper that Paul draws on, measures 28cm x 38 cm, a proportion very dissimilar to the ISO 216 (A5, A4, A*n*), proportions so widespread in contemporary visual environment. The size is significantly larger than A4, adding to the feeling of quality and uniqueness. In publishing, magazines or

Figure 3: *Sketches by Paul, 2011, (cropped views).*

books of larger sizes departing from the norm, are associated with quality. The paper chosen is of "conservation quality", meaning that its composition facilitates its preservation over a long period: it is made of 100 percent rag (cotton fibres) and weighs 300 grams per sheet. It has a NOT (not hot pressed) surface, that is a slightly relief paper texture, off white in color. These qualities influence how the drawing is perceived by the public at large, connoisseurs (curators, critics, collectors) and visual artists, associating the drawing's appearance with that of a traditional drawing canvas of quality.

General layout The placement and scale of the drawing on the sheet of paper influences the readability and the aesthetic effect of the drawing on the observer.

The lighting and pose Each time Paul is exhibited in a new location, a calibrating process is necessary to adapt Paul to the ambient light. In effect the calibrating stage consists of creating a contrast curve that will be be applied to the grayscale image of the sitter prior to sketching. For each sitter the light directed onto the face is reviewed by the person that manipulates Paul, and if necessary the light position and direction is adjusted. This stage is of great importance as lighting has a decisive impact on the character and aesthetic qualities of a picture.

Artist/Robot collaboration Paul's developer has spent more than 13 years of his adult life practicing drawing and painting at a professional level. As such Patrick, like any artist, has developed an expertise in the evaluation of drawings (see *fig.* 4). During Paul's development Patrick has evaluated the sketches with the same level of standards as if they were his own. During any artistic practice, the evaluation of the work is of primordial importance. The artistic practice has two stages: *a)* the development of an individual style which is achieved through research and practice that usually takes years, *b)* the application of this technique to produce artworks. Hence, we can say that Patrick has collaborated with Paul on the former phase of the artistic practice, as the succession of processes implemented in Paul are closely inspired by the strategies deployed by Patrick when sketching by hand, and Paul executes autonomously the later phase of the artistic practice.

A naive drawer Because it lacks memory of previous work, Paul has no concept of what a face is, nor what a human is and has no affective relation with the subject portrayed, and thus Paul can be considered a *naive* drawer. As such, its drawings are not "contaminated" by the knowledge of a subject, what Van Sommers calls the "conceptual bias" [VS84]. Studies have demonstrated this is one of the factors that causes misrepresentation amongst drawers [CB97].

The depiction of salient features When Paul draws lines, their paths are extracted from the responses of Gabor filter

Figure 4: *Sketch, Patrick Tresset, Pen on paper, 2003, (detail).*

banks [PK97] applied to an image of the subject at varying scales. Such filters are known to be good models of simple cells in the early visual cortex (V1) [JP87]. In their seminal Nobel prize winning work, Hubel and Wiesel observed that neurons found in V1, named simple cells, fire more rapidly when presented with line/edges at precise orientations [HW59]. In computational models of bottom-up visual attention such as Itti's [IKN98], Gabor filters are used to build one of the saliency maps based on orientation contrast. Areas that display high orientations disparities being salient regions. It has been observed that during the perception of natural scenes, salient areas attract the focus of attention. Interestingly in the context of a visuo-motor activity such as drawing a line, Coen-Cagli *et al.* have observed through eye-tracking experiments that fixations can be predicted from a orientation saliency map [CCCN*09]. Collomosse and Hall's work on painterly rendering effectively used image saliency as a factor to modulate level of detail rendered in NPR effects [CH02]. We can speculate that the use of what are in effect saliency orientation maps to plan the movements that Paul will perform in the first parts of the sketching cycle, contributes to the drawing being perceived in a manner similar to how a hand-made drawing would be interpreted.

The influence of decisions based on visual feedback Although there is no use of visual feedback for high level decisions in Paul's current behaviour, there is use of feedback at low level for motor control and during the shading process. The use of visual feedback to constrain and evaluate the random exploration at play during the shading process seems

to be sufficient to produce patterns that are perceived as not entirely due to chance. As such they might appear to be the result of an intentional process.

Paul's physicality Artists often cite the time/process capturing quality of drawing as an important factor contributing to the appeal drawings have on an observer. In a drawing each line is a direct record of the artist's hand motion. The drawing itself being a record of a specific sequence of actions performed by the drawer. And in effect a drawing is a precise physical record of the artist's intentions. Based on the recent discovery of the neural mirror system, it has been suggested that some of the actions deployed to create a drawing are mirrored in a part of the observer's neural system, and this could amplify the spectator's emotional response [FREEDBERG2007]. Paul's drawings are the results of a sequence of movements: as such they are the record of a process. Evidence that the traces which are part of a drawing by Paul were the results of movements can be found in the imperfections. Although these are not akin to imperfections a human would produce they have characteristics that could have only been produced by a pen in motion driven by an articulated arm. Furthermore the layering of successive lines and of successive patterns during the shading process adds to the drawing being percieved as the result/consequence of a sequence of movements/processes.

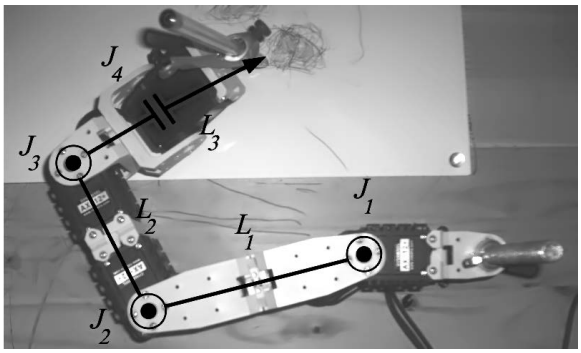
Scope for improvement Often when a naive observer or a non-drawer sees drawings produced by Paul at close range they interpret the patterns used for shading literally, describing them as "the robot going mad", "cobweb", "hairs" and so on. When drawings are observed at a distance this misinterpretation does not occur. The solution we have envisaged and recently tested is to implement shading behaviour controlled by visual feedback from the drawing in progress. This new implemention of the shading behaviour has shown to be successful, however this study needs further elaboration before being published in detail. Other improvements entail a full reimplemention and/or different better robotic hardware. This is currently in the works, but this future system will not be Paul anymore (i.e. is not the naive drawing entity described here), but rather one of its successors.

4. Description

4.1. Installation

Paul is composed of a left handed robotic arm holding a black Biro pen (*fig.*1, 6) and an actuated pan and tilt webcam (*eye*) bolted to a table. On one side of the table is a chair. Always present with the installation is an assistant: his/her role is to change the paper and give the signal to Paul that somebody is ready to be sketched which is achieved by covering the camera for ten seconds. The assistant may also give directions to the sitter and adjusts the light. Generally, when space permits, unsold sketches are displayed on the wall around or behind the installation (*fig.*5). Paul also performs a number of behaviours that are only pretences. These actions are implemented to make the audience believe that Paul is more alive than it is, and reinforce the relation between the sitter and Paul. For example whilst sketching, Paul often takes a look at the sitter, scanning the face with multiple saccades and fixations. In reality Paul draws from a single picture taken at the initial stage of the sketching cycle. Paul's eye also follows the tip of pen's movements during the drawing phases.

Figure 5: *Paul at Tenderpixel Gallery, London, 2011.*



$L_1 = 108mm., L_2 = 92mm., L_3 = 103mm.$

Figure 6: *Paul's arm*

4.2. Hardware

Paul is a robotic hand-eye system solely dedicated to the drawing activity. To remove as much complexity as possible we have constrained the arm's configuration to that of a three joints planar arm, with an extra joint to allow for lifting or bringing the pen in contact with the paper (*fig.*6). The servos used as actuators, AX-12 manufactured by Robotis [TP11], are relatively low cost and as such they present some drawbacks including a relatively low resolution and low feedback frequency. This lack of precision causes disparities between the path planned and the path executed by the arm.

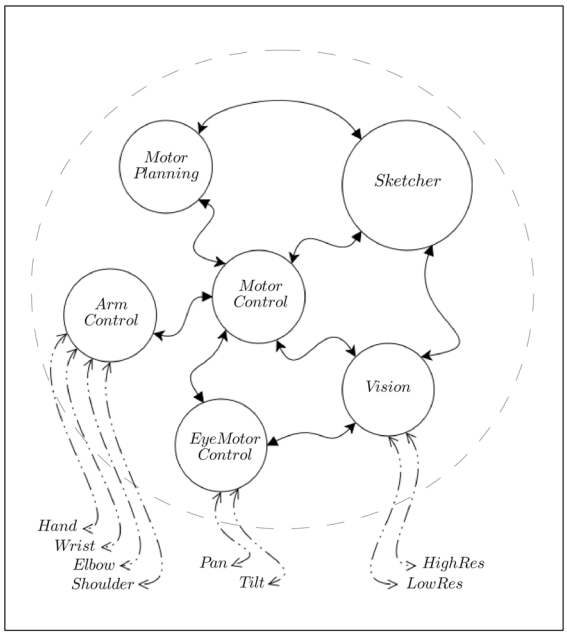


Figure 7: *Paul's processes overview*

4.3. Software

4.3.1. Robotic control and software architecture

Contemporary robotic software architecture is based on communicating concurrent distributed processes. In recent years we have seen the development of open source middleware dedicated to robotics such as ROS (Robotic Operating System) [QCG*09] and YARP (Yet Another Robotic Platform) [MFN06]. These frameworks help organise and manage processes and communication between sensors, processors, and actuators. One of the advantages of these frameworks is that they facilitate the components' reuse and have a large ecosystem of research teams that use these and continuously publish new components reusable for other projects. Paul is currently using YARP. The choice of YARP was motivated by the participation in the Barcelona Cognition Brain and Technology (BCBT2009) summer school, where YARP was introduced. An overview of Paul's current processes organisation is presented in *fig.*7.

4.3.2. Drawing cycle overview

1. Localise the sitter by moving the eye until a face is detected and focus the *eye* onto the sitter's face.
2. Take a picture, convert to graylevel and apply a contrast curve.
3. Draw salient lines with increasing precision.
4. Perform the shading behavior.
5. Execute the signing script.

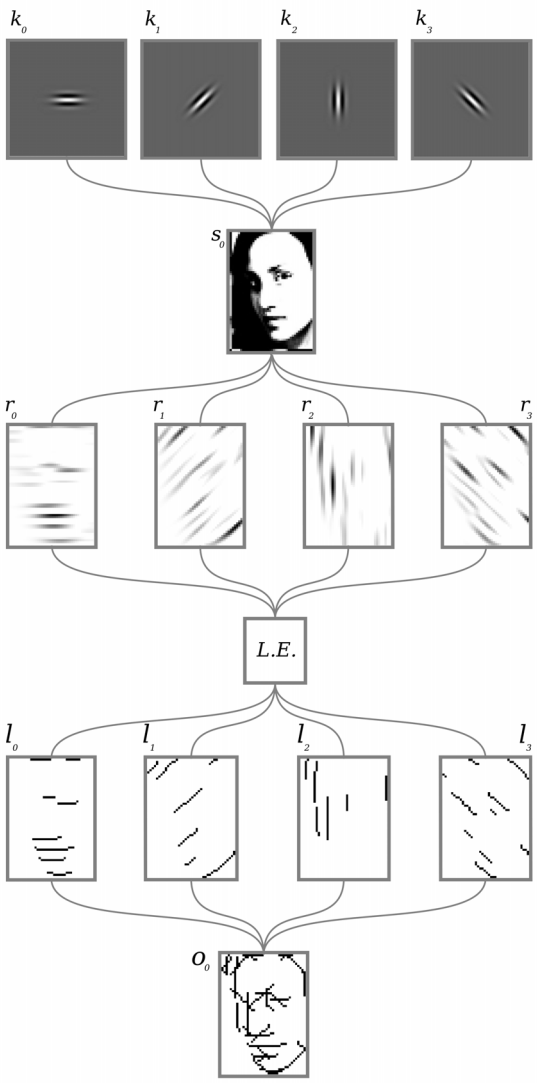
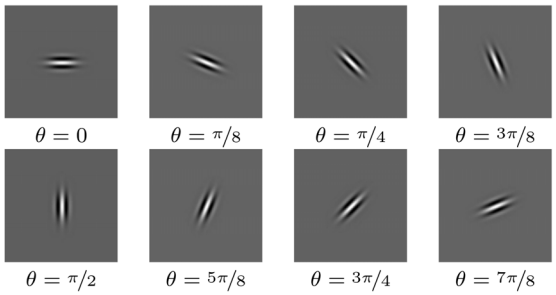


Figure 8: *Salient lines extraction*

Salient lines extraction process at level 0:
k_n : Gabor kernels with 4 orientations 0, 45, 90, 135 degrees, at level *(1, 2, 3), 8* kernels are used.
s_0 : Sitter's image at size 40 x 58 pixels, at each following level the image's width and height are multiplied by 2.
r_n *:* Results of the convolution of $k_n$and s_0, (for readability, in this illustration the image's gray levels are inverted).
l_n: Visualisation of the lines extracted from r_n.
o_0: Visualisation of the combination of r_0, r_1, r_2, r_3.
L.E.: Line extraction process; *i)* r_n is thresholded, *ii)* connected components (blobs) are extracted from the binary results, *iii)* A medial axis transform [FLL92] is applied to each blob, *iv)* Each medial axis is then represented by an array of points to be sent to the *Motor Planning* process.



$$g_{\lambda,\theta,\varphi,\sigma,\gamma}(x,y) = \exp(-\frac{x^2+\gamma^2 y'^2}{2\sigma^2})\cos(2\pi\frac{x'}{\lambda}+\varphi)$$
$$x' = x\cos\theta + y\sin\theta \quad y' = -x\sin\theta + y\cos\theta$$
$$\gamma = 0.5,\ \lambda = 5,\ \sigma = 2.5,\ \varphi = \pi$$

Figure 9: *Gabor kernels*

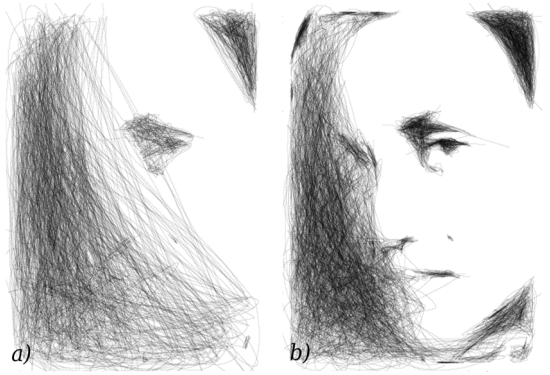


Figure 10: *Shading Process*

Face localisation OpenCV's [Bra00] object detection library, based on Viola and Jones' work [VJ01] and improved by Leinhart [LM02] is used for face detection.

Salient lines extraction Lines are extracted from the result of the convolution of Gabor filters [PK97] at multiple orientations (*fig.*9) with each level of a pyramid representation [CS87] of the sitter's image. A visualisation of the process at level 0 is presented in *fig.*8. The use of Gabor filters to extract lines is motivated by a number of factors:

- Biologically motivated [JP87].
- Stylising effect: as a discrete number of orientations is used the curves are constructed from lines for a limited set of orientations. This limitation is a distinguishing feature desirable in hand drawings [Raw87]. In the same manner as a restricted colour palette is used in a painting, this reduced orientation palette has a stylising and harmonising effect.
- Related to the manner curves are measured to be depicted: one common manner to measure observed curves is to imagine/visualise the tangents.
- One of the effects of using Gabor responses is that salient portions of curves (high curvature) are accentuated. This is desirable as not having curves depicted in a uniform manner adds to the aesthetic richness of the drawing.

Shading behaviour When drawing, shading can be rendered in various manners, but it generaly consists of filling an area with patterns at different scales/concentrations. If the pattern has a perceptual orientation, it has to be related to the direction of the plane being depicted. If the pattern used has no dominant perceptual orientation, only the graylevels are represented. Often drawers take advantage of humans visual limitation by rendering a discrete number of gray levels that will be perceived as a smooth gradation from dark to light. The number of gray levels depicted with such a strategy varies, but often 5 values are rendered: white (absence of pattern), light gray, mid gray, dark gray, black. The following strategy produces non oriented overlapping patterns, and takes into consideration possible convexities and holes.

The sitter's image is thresholded at four different levels providing five binary maps. The map corresponding to white regions is then discarded. For each of the four remaining maps an array of connected components (blobs) is extracted. For each blob a set of points is chosen from which a cubic spline will be interpolated. The points are chosen randomly one by one to form a set sampling the blob. From an internal model of the blob (a two dimensionnal binary array), visual feedback is used to evaluate if the latest chosen point should be added to the set or if another point should be randomly considered. Criteria for evaluation are: *i)* the distance between the two last points should be less than a value that is proportional to the blob's size, *ii)* the percentage of line segment traced between the two last chosen points that lies outside of the blob should be under an *a priori* selected threshold value. The search for new points is interrupted when the length of the path going through all the considered points in the set reaches the stopping criterion, a value proportional to the gray level considered and the blob's area size. The path is computed by interpolating a cubic spline for the set of points and drawn onto the image of the blob. Feedback detects if a relatively large area of the blob has not yet been drawn upon, which triggers a new line drawing step for this smaller sub-area now considered as a new blob. In *fig.*10 a simulated shading process is presented: *a)* presents the outcome of the shading process implemented without constraint nor feedback evaluation, while *b)* presents the outcome with the current constraints and feedback evaluation.

5. Conclusion

This paper presents Paul and its sketches. Although the algorithms driving Paul are relatively simple and not particularly novel, the way they are combined is of interest as the

sketches Paul produces are considered by professionnal as being of artistic value, which is unusual for computer generated figurative drawings. We have presented a comprehensive range of factors that may explain why Paul's sketches are perceived as being of interest to a specialised audience, and the public at large. Although no further major developments are planned for Paul, a number of public exhibitions are scheduled for the coming two years. The next important milestone will be the implementation of another embodied system, currently under study. This new robot will take into consideration and be influenced by visual feedback at all the stages of the drawing process. This new system will also be influenced by levels of knowledge of the human face, e.g. proportions. We expect the drawing style of the new system to be significantly different from Paul's current style.

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