Democratising DMIs: the relationship of expertise and control intimacy

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ABSTRACT

An oft-cited aspiration of digital musical instrument (DMI) design is to create instruments, in the words of Wessel and Wright, with a 'low entry fee and no ceiling on virtuosity'. This is a difficult task to achieve: many new instruments are aimed at either the expert or amateur musician, with few instruments catering for both. There is often a balance between learning curve and the nuance of musical control in DMIs. In this paper we present a study conducted with non-musicians and guitarists playing guitar-derivative DMIs with variable levels of *control intimacy*: how the richness and nuance of a performer's movement translates into the musical output of an instrument. Findings suggest a significant difference in preference for levels of control intimacy between the guitarists and the non-musicians. In particular, the guitarists unanimously preferred the richest of the two settings whereas the non-musicians generally preferred the setting with lower richness. This difference is notable because it is often taken as a given that increasing richness is a way to make instruments more enjoyable to play, however, this result only seems to be true for expert players.

Author Keywords

expertise, learning, control intimacy, richness, sensorimotor skill

CCS Concepts

•**Applied computing → Sound and music computing;** Performing arts;

1. INTRODUCTION

Within NIME and related research fields, much discussion has centred around richness of control, the level of detail of control that a performer has over an instrument. It has been proposed for many years that richer mappings between control input and sound output are better [25], and much design effort has gone into this idea. Yet in practice, the design of digital musical instruments (DMIs) involves balancing two factors that can often seem at odds with one another: the steepness of the learning curve that a performer has to climb to make music with an instrument, and control intimacy, how the richness and nuance of a performer's movement translates into musical output.

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In this paper we aim to interrogate the idea that 'a richer instrument is a better instrument'. We designed a study involving two different groups of players (guitarists and non-musicians), which compared two levels of richness (audio-rate coupling between strings and sound model, and note-based triggers) within the same guitar-derivative DMI. We found that although the experienced musicians unanimously preferred the richer instrument, this appears to be only true for this group. The non-musicians were more ambiguous in their preference for the instruments, but perhaps surprisingly, tended towards the less rich instrument overall. This paper aims to clarify the processes that led to this preference by analysing interviews conducted with the performers and their gesture language with different levels of richness.

2. RELATED WORK

Theories of sensorimotor skill acquisition generally agree that the process passes through a number of qualitatively different stages as the learner progresses from novice to expert [2, 7]. The stage-based approach is assumed to hold across different skill development domains [5] including learning musical instruments [12]. A classic model of the stage-based approach to skill acquisition is by Fitts [6] which consists of three stages:

- *cognitive*: the performer has a task broken down into small components that are not related to the whole. Performance characterised by high error, high variability and a detachment of the individual components from the whole task.
- *associative*: follows an extended period of deliberate practice. The performer can associate actions with successful results, makes fewer errors, becomes more aware of her errors through a (partial) understanding of the whole task.
- *autonomous*: reached through further deliberate practice. The performer can carry out the components of the skilled action at a faster pace and without conscious attention and can focus on higher-level aspects of the task.

Learning an instrument involves internalising how action translates to sound, which is initially acquired by exploring and manipulating the instrument with somewhat arbitrary actions that lead to unexpected results [9], what Wessel called the 'babbling' stage due to its similarities to the manner in which young children learn to form words [24]. A process of experimentation, exploration, repetition and association, builds an internal model that captures the relationships of the actions the instrument affords and the resultant sound [12]. Once the musician progresses to a level of expertise they do not need to focus attention on the individual operations of manipulating an instrument, instead focusing on higher-level musical intentions: the instrument becomes a 'natural' extension of the musician's body and no longer an obstacle to an embodied interaction with the music [19].

Traditional musical instruments are often given as examples of tools where the relationship of gesture and sound is both intuitive and complex: Dobrian and Koppelman [4] emphasise the importance of relating DMI design to its acoustic ancestry for this reason. Unlike acoustic instruments, DMIs can boost a performer's ability to achieve musically complex results by partially shifting the responsibility for sound production away from their sensorimotor ability and to the digital system. How intuition, complexity and the development of expertise are balanced in DMI design has been the focus of much research in this field.

2.1 Instrument efficiency

Efficiency in regards to musical instruments can be considered as the instrument's ability to transfer input gestures to musical sound [11]. Jorda posits that the kalimba, at least in the first stages of learning, is a more efficient instrument than the piano. Whereas a piano has many notes a kalimba has few and they are all the 'right notes'; its form intuitively encourages the performer to play with their thumbs; once the kalimba is held in both hands it is clear which thumb should be used to control which notes. So instrument efficiency depends on the relationship between the complexity of the input gestures and the complexity of the resultant sound output, and the ease with which a performer can get from one to the other. Jorda illustrates the balance between challenge, frustration and boredom by comparing these instruments and suggests that new instruments should adhere to Wessel and Wright's 'low entry fee with no ceiling on virtuosity' [25].

Pardue [20] states 'it is in learning where DMIs can have an inherent advantage over traditional instruments', proposing the term *complexity management* to describe the notion that instrument efficiency can be progressively managed over time in order to maintain a rewarding learning experience at all levels of expertise. By guiding the novice user towards less complex musical output, certain techniques can be isolated for technical practice. This approach could also provide more immediate access to less formal musical practice such as improvising or 'jamming' with other musicians, activities which McPherson and McCormick [15] show help with the level of cognitive engagement during musical practice.

2.2 Designing affordances

When designing DMIs the process is often conceptualised as the creation of affordances and constraints towards music making [13]. In a recent paper discussing embodied control in HCI, Tuuri et al. [23] distinguish between *push effects* which force or guide the user to particular choices, versus *pull effects* which relate to an ease of conceiving how action relates to a particular output, as characteristics of an instrument's affordance structure. Through these effects a performer is provided with control of an instrument, while equally the instrument enforces control on the performer. Jack et al. [10] propose a model of DMIs that is based on projection from a high-dimensional space of body movement to a reduced space of sonic and kinematic features and behaviours. In this model the instrument represents a bottleneck in the flow of gestural information, which is positioned through design choices. In this study, we are investigating the influence of different *widths* of bottleneck on a performer's experience – each of the instruments we created allow different levels of detail to be carried into the sound output, and we are interested in how this folds back on the gestures that the performers use.

2.3 Intimate control and expression

Control intimacy, as first introduced by Moore [17], can be described as a performer's perceived match of the behaviour of an instrument and their psychophysiological capabilities when controlling the instrument. Intimate instruments (such as the voice, violin, sitar, flute) allow the micro-gestural movements of the performer to create a wide range of affective variation in the control of musical sound. Moore identifies MIDI as suffering from a deficit of intimate control in its discretisation of musical performance into a sequence of note-on, note-off with velocity. Wessel and Wright expand on Moore's notion of control intimacy and its relationship to virtuosity, stating that 'a high degree of control intimacy can be attained with compelling control metaphors, reactive low latency variance systems, and proper treatment of gestures that are continuous functions of time' [25][p. 2]. They propose that high control intimacy can encourage performers to continually develop their skill on an instrument and their personal style: low intimacy implies that the communication between a performer and a device is poor and there is a barrier to expressive performance, and hence engagement.

3. STUDY

In this study, we aimed to ask 'does a richer instrument necessarily mean a better instrument?', and explore how prior experience and expertise relates to this. Specifically, we aimed to investigate the effects of modulating the richness of a plucked-string guitar-based instrument on the experience and gestural language of guitarists and non-musicians.

3.1 Instrument design

We designed two guitar derivative DMIs with different form factors but identical sensor topologies, based on real guitar strings with piezo sensors. One follows the shape and form of a guitar and is held with a strap, with the right hand resting over the strings and left hand holding the neck. The 'tabletop' version was designed to follow design cues from boutique music hardware such as modular synth controllers. Figure 1 shows the two instruments.

Figure 1: Two instruments used for this study: guitar form (L) and tabletop form (R)

3.1.1 Physical construction

Both instruments were designed to be played using similar techniques to a guitar or other strummed string instruments. They feature six buttons mapped to six chords. The buttons on the guitar form are placed on the neck, around where the lower frets would be on a traditional guitar neck.

The tabletop version features the buttons on the lower left corner, with the strings placed at a 45 degree angle, as this was found to be the most comfortable for strumming with the right hand. Both instruments featured a method of switching between the two sensor mappings described below.

The physical construction of the string modules involves six short lengths of .040 gauge bass guitar string held loosely over a 'strummable area' of about 10 cm. At one end, the strings are terminated over a block of felt-covered foam, with six individual bridge-pieces at the other with integrated piezo disc sensors, and held to a low tension using adjustable zither pins. This provides a strong acoustic signal when strummed or plucked, similar to the attack of a plucked string on a guitar. The thickness of the strings and low tension provides a short decay and fewer resonant properties than a typical guitar string held to tension.

3.1.2 Sensor mappings

Both variations of the instrument use the Karplus-Strong algorithm to simulate six virtual strings which, individually excited using signals from the individual piezo sensors. We used a Bela board [14] for the sensing and string modelling to create a high-performance, low latency embedded instrument in each case. The only difference between the two variations is the mapping of the piezo signal to the excitation of the virtual strings. The two mapping structures used are 'audio-rate' excitation and 'sample triggering':

Audio-rate excitation: Excitation of a virtual string model using a real-time audio signal has been implemented and documented in previous NIME research, including the Kalichord [21], BladeAxe and PlateAxe [1] and Caress instruments [16]. Such instruments allow intuitive control over the resulting sound by varying the way the physical model is excited (plucking hard or soft, or with different materials). Our instruments follow a similar principle, but use dampened strings terminated over piezo sensors to drive the virtual string models. This allows the use of natural strumming and plucking gestures, as well as less traditional ones such as tapping, scraping or stroking the strings, which have musically meaningful results in the resulting audio signal.

Sample triggering: The sample triggering version uses the same synthesis technique but dramatically reduces the amount of achievable variation in input signal. Rather than passing the audio signal directly to the virtual string algorithm, a peak detection algorithm is used to trigger a pre-recorded pluck recording whenever an amplitude peak is reached. The recorded pluck was taken directly from the piezo audio signal, so is directly comparable with the audio-rate version, however the timbre and dynamics remain static independent of input gesture.

3.2 Study Design

Participants were asked to compare two versions of the same instrument. We used a combination of improvisation/exploration and prescribed musical tasks. We also collected qualitative data using questionnaires and structured interviews at two points during the study and audio and video recorded the whole session.

We recruited 32 Participants (16 'competent' guitarists and 16 non-musicians). Participants were asked to self-identify at the recruitment stage using the following statements: 'you are comfortable strumming and playing along to a tune' (competent guitarists) and 'you have no or very little experience playing an instrument'. We asked participants to complete the self-report questionnaire section of the Goldsmiths Musical Sophistication Index (GoldMSI) test battery [18].

The full study was designed to investigate several factors, some of which are not relevant to this paper. This involved a comparison of the physical form of the instruments (the tabletop and guitar-shaped forms described in Section 3.1), as well as sensor topologies (the string modules described previously, and a touch sensor variation). The results of the comparison between form and sensor topology are presented elsewhere [8]. In this paper, we are concerned only with those instruments which featured the 'string' sensor topology. The results presented here concern the comparison of these instruments in either 'sample-triggering' or 'audio-rate' variations.

3.2.1 Musical tasks

Participants were instructed first to improvise and explore with the instrument in the sample-triggering setting for seven minutes. They were then given a further seven minutes to rehearse and perform an accompaniment to a recording of a folk song. We recorded a piece taken from the folk-RNN songbook [22] for this purpose, arranged for fiddle and electric bass. The chord structure of the song used chords I, IV and V in the key of G. We added coloured stickers to the buttons to indicate these chords and printed a colour-coded score for participants to follow while playing. We also produced a video file displaying the chord colours and positions on screen as they appeared in the score, in a similar manner to the Guitar Hero games. Participants were allowed to use either or both of these methods to follow the backing track but were encouraged to use the printed score if they felt comfortable to do so. The buttons and score are presented in Figure 2.

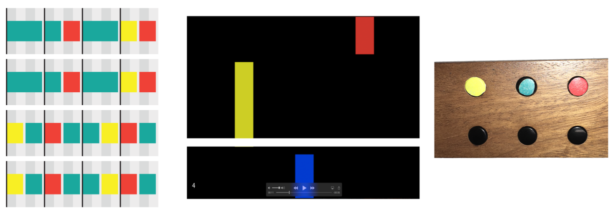

Figure 2: L-R: colour-coded paper score, screenshot of on-screen chord visualiser, colour-coded buttons

For the final musical task, we instructed the participants to switch to the audio-rate variation of the instrument using a switch on the instrument's enclosure. They were then given ten minutes to improvise and explore with the instrument. No further score-following tasks were given.

3.2.2 Questionnaire and structured interviews

After the score following task we conducted structured interviews with the participants asking questions related to the techniques they used and their overall impression of the instrument in the sample-triggering variation. Following the final musical task with the audio-rate variation, another structured interview took place, this time focusing specifically on differences and similarities between the two settings. We then asked participants to indicate their preference for either setting using a horizontal on-screen slider with 'setting 1' (sample-triggering) on the left and 'setting 2' (audio-rate) on the right. This produced a value from 0-100, with 0 indicating strong preference for setting 1, and 100 indicating strong preference for setting 2.

4. FINDINGS

Our findings consist of a quantitative measure from the comparitive rating of each setting and a pair of thematic analyses: the first on the interviews conducted with the participants, the second on their gestural language while playing the instrument.

4.1 Participant data

We recruited 32 participants, 16 in each group. 19 participants were male (13 guitarists and 6 non-musicians), and 13 were female (3 guitarists and 10 non-musicians). Participant age ranged from 18 to 62 with an average 32 years old. The average GoldMSI scores for each group were 89 (SD = 11, minimum = 72) for guitarists and 55 (SD = 11, maximum = 70) for non-musicians. The minimum and maximum show the proximity of the two groups.

4.2 Ratings

Figure 3 shows the comparative rating of the settings by each group. A paired t-test on the comparative ratings of the settings from each group found a significant difference between groups (t = 5.6833, df = 16.731, $p < .01$). All 16 guitarists rated the audio-rate setting as better, whereas there was more disagreement in the non-musician category with 6 rating audio-rate as better and 10 rating sample-triggering as better. We also tested for an effect of the different global forms (guitar-shaped vs. tabletop) but found no significant effect, meaning that the difference in rating was driven by the difference between the settings.

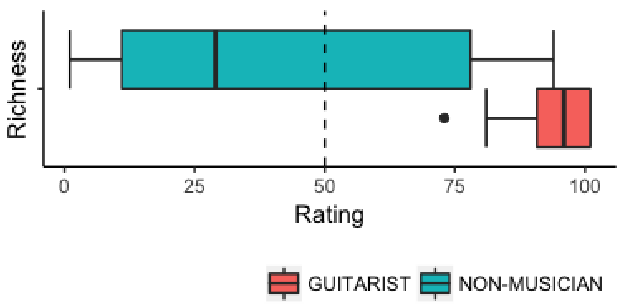

Figure 3: Median and IQR ratings of setting 1 (sample-triggering represented by 0 on the y-axis) and setting 2 (audio-rate represented by 100 on the y-axis) for all 32 participants.

4.3 Participant reasoning

We performed a thematic analysis on the transcripts from the structured interview with a focus on reasoning in relation to the following themes: sound, technique, instrument behaviour, relation to existing instruments or interfaces. Table 1 presents some sample quotes that are representative of the reasoning of each group.

The 6 guitarists were quick to critique the sample-triggering variation at the end of their first session, even without the knowledge that a richer mapping would be introduced later in the study. Most of the comments focused on the lack of timbral expression and the flatness of the articulation on the instrument in comparison to what they were used to on a traditional guitar. The addition of these capabilities with the audio-rate setting was mentioned by 12 participants in this group. The audio-rate setting's ability to support existing technique was also a reoccurring theme, with particular reference to fingerpicking and articulation. 6 members of this group also made reference to the 'feel' of the instrument as more 'guitarry' or 'natural' in comparison to sample-triggering: "*setting 2 really uses your knowledge of guitar. Compared to setting 1 where the strings are not behaving as strings.*"

The non-musicians who preferred sample-triggering generally reported differences between the two settings related to 'clarity' and 'power' in comparison to the more 'fragile' or 'far away' audio-rate setting. Sample-triggering was described by 9 in this group as easier to generate sound with: comparisons of the force required to create sound from the instrument were mentioned, with sample-triggering commended for its ability to create a loud sound with little effort using a diverse set of playing techniques, whereas the audio-rate setting was referred to as difficult, hard, or requiring too much pressure. There were also 4 non-musicians (1 who preferred sample-triggering, 3 who preferred audio-rate) who stated that they noticed very little or no difference between the two settings and so just went with their gut feeling.

4.4 Techniques

We performed a further thematic analysis of the video footage, focusing on identifying the different sets of gestures each participant used in their right hand during the musical tasks. These observations are presented in Table 2. Our interest was in comparing the diversity of gesture usage in each group to identify correlations with their given preference.

From Table 2 we can see that there was no clear distinction between the groups in terms of overall diversity of gestures: both used a similar variety and spread of gestures although the more 'guitar-like' techniques (strumming as if holding a plectrum, finger-style) occurred more frequently with the guitarists.

5. DISCUSSION

Our findings complicate the notion that 'a richer instrument is a better instrument'. The guitarists were unanimous in their preference for the richer setting, which is unsurprising as the audio-rate setting more accurately translates the existing techniques of guitar players to musically meaningful timbral and dynamic effects. What was less expected was the ambiguity of response amongst non-musicians, and their tendency towards the less rich instrument overall.

From the structured interviews we can piece together a picture of why this difference in opinion might exist: guitarists were able to speak at length of a lack of detail, flattening of nuance and general shortcomings of the triggering routine. For this group there was a wasted reserve of gestural potential that had no effect on the musical output of the instrument. Many of the non-musicians however, were complimentary of the sample-triggering setting for its clarity and strength of sound. This group frequently spoke of the audio-rate setting as quieter (which was true for soft playing but if sufficient energy was put into the instrument then it could be louder than the sample-triggering), more delicate, and harder to produce a satisfactory sound with.

5.1 Efficiency and richness

If we return to Jorda's notion of instrument efficiency [11] we could say that the sample-triggering setting is more efficient than the audio-rate setting. The complexity of musical *input* is matched for both settings: both have reasonable coverage of the techniques used to play guitar, and the physical layout and dynamic material behaviour of the strings do not change with the settings, supporting the same base of gestures. It is in the musical *output* complexity that the settings differ, with the sample-triggering setting projecting a rich and nuanced set of input gestures to a reduced set of musical features in the sound output. The audio-rate setting retains the spectral relationship between input and

Table 1: **Selected responses from the structured interview.**

Timbre	**Amplitude**	**Technique**	**Realism**	**Behaviour**
		Guitarists		
"There was a definite tonal difference"	*"with setting 2 you can play soft, and you can play hard"*	*"all the things that I do worked on setting 2 but didn't necessarily work on setting 1"*	*"It really uses your knowledge of guitar. Compared to setting 1 where the strings are not behaving like strings"*	*"Setting 2 was responding to touch much more delicately"*
		Non-musicians		
"Setting 1 was like listening to a guitar in a concert, but setting 2 was more like listening to something on my computer"	*"Setting 1 was louder and brighter to me"*	*"You need to put more pressure with your hands with setting 2, it's harder to generate the sounds while with setting 1 you can just touch the strings and create the sound"*	*"There wasn't much difference between the two, but with the first setting everything I did made a difference, with the second one everything sounded more fragile in a way."*	*"My tapping didn't trigger the string rather, what I was triggering was the sound of the string itself"*

Table 2: Analysis of gesture occurrence for each group and each setting. Column corresponds to number of participants who used each gesture under each setting. The gesture analysis of the free improvisation with setting 1 (sample-triggering) and setting 2 (audio-rate).

		Non-musician		Guitarist	
	Setting:	1	2	1	2
Strumming	Strumming with a single finger	14	12	9	4
	Strumming with hand like holding plectrum	7	6	13	11
	Strumming with multiple fingers	5	5	2	2
	Rake / 'flamenco style' strum	2	1	1	1
Plucking	Slow plucking with fingers / thumb	16	12	11	1
	Fingerpicking (finger-style)	8	8	13	11
	Plucking with hand like holding plectrum	1	3	2	0
Scratching/Tapping	Tapping individual strings	10	6	8	3
	Tapping multiple strings with flat finger	6	2	4	3
	Pushing down on strings	6	1	2	—
	Scratching / swiping strings	2	8	4	3
	Tapping bridge pieces	1	2	6	4
Testing	Damping strings / attempting to damp strings with palm	6	4	4	2
	Strum / pluck / tap at different points along the string	6	3	4	4
	Plucking while pressing down/muting strings	1	5	4	—
	Observably testing triggering threshold	3	N/A	4	N/A
	Observably testing dynamic range	N/A	2	N/A	3

output and so requires nuanced control of the strings in order to get a nuanced output, whereas the sample-triggering setting can work with a much lower level of definition at the input: any energy above a certain threshold is transformed into an impulse and the spectral signature of that gesture is disregarded. The bottleneck [10] that the instrument represents to the interaction can be imagined as wider in this case in comparison to sample-triggering: more of the performers' gestural language can be projected through the instrument. A wider bottleneck might inherently mean lower efficiency: the fact that a greater amount of control input complexity can affect the output means that the performer becomes responsible for that extra level of control.

This can also be viewed in terms of required *effort*. Both settings transfer energy from input to output (the kinetic energy of the performer to the sound energy of the instrument). Effort relates to the total *amount* of energy needed to achieve a result. The sample-triggering setting required much less physical effort to achieve an equivalent note to the audio-rate setting. While effortful interaction is proposed as a valuable thing in DMIs [3], in the case of non-musicians here the relative lack of effort was perceived as attractive.

5.2 Gestural behaviour

The similar spread in gestures between both groups, alongside the stark difference in opinion in terms of setting preference, shows how the affordances and constraints of the instrument were found in a similar manner for both groups, but meant different things to them depending on experience. The non-musicians were concerned with efficiency of sound production and the easiest way to generate a note. With the sample-triggering setting they were quickly drawn to the *pull effects* of the instrument – the places where they were enabled in their control [23]. With the audio-rate setting the instrument had a different affordance structure which, for many in this group, manifested as *push effects* – they were forced to use a particular set of gestures requiring more nuance and effort than they were capable of to achieve a satisfactory musical result.

5.3 Learning curves

For the experienced guitarists that are used to navigating input complexity there is no advantage in reducing it, in fact many of the guitarists negatively reported the lack of output complexity from the sample-triggering setting. In the case of the non-musicians there does however seem to be a use in reducing the output complexity (and hence increasing the efficiency of the instrument). This could be partly due to the learning curve that each instrument has. Whereas the guitarists already know a large amount of techniques that can be used to play the guitar, and so are able to quickly make sense of the audio-rate setting, non-musicians want a more direct route to producing musically satisfying sound with the instrument and so prefer the faster learning curve of the more efficient sample-triggering. We can consider the switch between settings as a kind of 'complexity management' [20] that provides non-musicians with a shortcut to taking part in a musical activity as a performer.

5.4 Study design

There is a possible effect of the study design on our observations from the fact that Setting 1 came first. Guitarists complained about the limitations of Setting 1 before having knowledge that a richer setting was coming later in the study, which is a good support for our findings. With the non-musicians, some of the effects could be explained by the fact that they were already familiar with Setting 1 when they switched to Setting 2. Differences in musical expertise (from GoldMSI) within the two groups is another point that could benefit from further investigation.

6. CONCLUSIONS

In this paper we explored the notion of control intimacy and how it relates to instrumental expertise and prior experience. We set up a study to explore the effects of increasing the 'richness' of an instrument for both experienced musicians and novices. Our results support the notion that *for experienced musicians*, richer instruments are preferable and more suitable for performance. This is possibly due to the preservation of the full spectrum of gestures that have a meaningful effect on the musical output. When designing for non-musicians, however, the role of richness is less clear. There was a greater spread in overall preference for the two instrument variations, with a tendency towards the less rich version. Viewing this variation as the more musically efficient of the two settings, especially in the hands of a non-musician, our findings suggest that an instrument which requires less physical and mental effort from the player can lead to more enjoyable experiences for beginners even if it has a more restricted space of possibilities.

In this paper we have only analysed the 'first contact' a performer has with an instrument rather than a longitudinal evolution of performer and instrument. Going back to the notion of 'complexity management' and the value of learners taking part in more informal, less technique-oriented musical situations, we might find a compelling argument for introducing similar methods of adjusting the richness on future instruments to streamline non-musicians into musical contexts as performers. Future studies on this subject might therefore incorporate a longitudinal approach and a sliding scale of control intimacy.

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