RESEARCH QUESTIONS

Research in crowdsourcing has spent the better part of a decade exploring how to grow the limits of crowdsourcing, finding the boundaries of crowd work and microtasks. This has largely involved iteratively identifying challenges to increasing complexity and overcoming them through novel designs of work–flows and processes (e.g. [9, 82, 54]). The question that has emerged then has been *whether* there are limits to crowdsourcing — and if so, what factors determine them. Through this lens, a number of contributions to the field have pushed the boundaries of crowd work.

The exploration of crowdsourcing's potential and limits has principally looked at manipulating and extending along three dimensions: First, what are the complexity limits of crowd work. Second, how far can work be decomposed into smaller microtasks. And third, what will work and the place of work look like for workers. We'll explore these aspects of crowdsourcing, discussing the extents to which work can be decomposed, contextually abstracted, and made more resilient to attrition of various forms. We'll also point to corresponding piecework literature addressing these aspects. [MSB: Our goal will be to use that literature to inform answers to the questions about crowd work (or something like that)] Finally, we'll discuss how these elements will serve to constrain the upper and lower bounds of crowdsourcing as it relates to the question of the furthest limits of crowdsourcing.

Identifying the Complexity Limits of Crowd Work

A key question to the future of crowd work is *what* precisely will become part of this economy. Paid crowdsourcing began with simple microtasks on platforms such as Amazon Mechanical Turk, but microtasks are only helpful if they build up to a larger whole. So, our first question: how complex can the work outcomes from crowd work be?

Crowd work's perspective

Crowdsourcing research has spent the better part of a decade proving the viability of crowdsourcing in complex work. Unless crowdsourcing can demonstrate viability for meaningfully complex tasks, the argument runs, it will be incapable of ensuring a pro–social outcome for work and workers [55]. Kittur et al. first opened the question of whether crowdsourcing could be used for goals that are not simple parallel tasks [54]. Their work demonstrated proof–of–concept crowdsourcing of a simple encyclopedia article and news summary — tasks which could be verified or repeated with reasonable expectations of similar outcomes. Seeking to raise the complexity ceiling [77], researchers have since created additional proof–of–concept applications and techniques, including conversational assistants [59], medical data interpreters [59], and idea generation workflows [111, 109, 110], to name a few examples.

To achieve complex work, this body of research has often applied ideas from Computer Science to design new crowdsourcing workflows. Beginning with a goal that has presented significant challenges for computers, the researcher leverages an insight from Computer Science (for example, MapReduce [54] or sequence alignment algorithms [58]) and arranges humans as computational black boxes within those approaches. This approach has proven a compelling one because it leverages the in–built advantages of scale, automation, and programmability that software affords.

It is now clear that this computational workflow approach works with focused complex tasks, but the broader wicked problems largely remain unsolved [85]. As a first example, idea generation shows promise [111, 109, 110], but there is as yet no general crowdsourced solution for the broader goal of invention and innovation [30]. Second, focused writing tasks are now feasible [52, 9, 78, 96, 1], but there is no general solution to create a cross–domain, high–quality crowd–powered author. Third, data analysis tasks such as clustering [22], categorization [6], and outlining [68] are possible, but there is no general solution for sensemaking. It is not yet clear what insights would be required to enable crowdsourced solutions for these broader wicked problems.

Restricting attention to non–expert, microtask workers proved limiting. So, Retelny et al. introduced the idea of crowdsourcing with online paid *experts* from platforms such as Upwork. Expert crowdsourcing enables access to a much broader set of workers, for example designers and programmers. The same ideas can then be applied to expert "macro–tasks" [21, 37], enabling the crowdsourcing of goals such as user–centered design [82], programming [62, 28, 19], and mentorship [95]. However, there remains the open question of how complex the work outcomes from expert crowds can be.

Piecework's perspective

[al2: I'm not sure that this really stays close to the three case studies that emerged as major threads (now in the piecework lit review). Should I refactor/rewrite this to make it more relevant?] Measurement also limited the complexity of piecework: only tasks that could be measured and priced could be completed via piecework. When Brown investigated what limited the adoption of piecework in industries that otherwise gravitated toward it (e.g., railway engineers), the homogeneity of tasks arose as a major contributing factor [14]. Graves concurs via a case study of the Santa Fe Railway, which used "efficiency experts" to develop a "standard time" to determine pay for each task at the company informed by "thousands of individual operations" [32]. One might conclude from Graves's observations that complex, creative work — which is inherently heterogeneous and difficult to routinize — would be unsuitable for piecework.

Piecework was limited to tasks that could be clearly evaluated. For example, the roles required to facilitate piecework in the early 20th century included "piecework clerks, inspectors, and 'experts"' [32]. Hart argue that evaluation is the ultimate complexity limit: at some point, evaluating multidimensional work for quality (rather than for quantity) becomes infeasible. In their words, "if the quality of the output is more difficult to measure than the quantity [. . .] then a piecework system is likely to encourage an over–emphasis on quantity produced and an under–emphasis on quality" [40]. Complex work, which is often subjective to evaluate, falls victim to this criteria.

This focus on measurement and tracking had consequences. Graves suggests that the first sparks of scientific management could be found in piecework: the approach of paying workers for each piece of output necessitated the rigorous tracking, measurement, and training of workers for which scientific management became famous [32]. If true, the concurrent upswing of scientific management and Fordism through the first two–thirds of the 20th century alongside piecework was not only understandable, but predictable [39].

Piecework researchers also argue that, in addition to constraints on the kind of *work* that's amenable to piecework, only certain kinds of *organizations* were amenable to piecework. Researchers detail three organizational criteria. First, Brown argues that piecework "is less likely in jobs with a variety of duties than in jobs with a narrow set of routinized duties" [14]. Agell points out the phenomenon here as a market effect: "in an environment with multi–tasking, pay schemes based on tightly specified performance may induce workers to neglect tasks that are less easy to measure" [2]. Second, complexity was limited by access to capital to create the necessary infrastructure. As Graves reports, only the largest and most wealthy railroads had the resources necessary [32]. Third, organizations required capable managers in charge of the pieceworkers. The West Virginia mines, for example, hired foremen to be the intermediary between upper management and the workers [12]. These foremen were responsible for allocating resources and understanding when and how to modify work as necessary [107]. So, in sum, organizations historically could only take advantage of piecework if they had homogeneous work to be done, access to capital to purchase the necessary equipment, and the ability to hire people who could serve as intermediaries between pieceworkers and management.

The research seems to suggest that it was difficult to apply piecework to more skilled work, particularly because maximizing the advantages of piecework seemed to reward smaller, more constrained, more narrowly–trained tasks, and only in organizations that could pay for the equipment and people to enable it. For most of the 19th century, piecework was applied almost exclusively to farm and textile work. Work was simple and widely understood — farm workers didn't need to be trained on how to plow fields, or birth foals; seamstresses knew how to sew together denim [18, 84].

Comparing the phenomena

The research on piecework tells us that we should expect piecework to thrive in industries where the nature of the work is limited in complexity [14]. Given the flourishing of on–demand labor platforms such as Uber, AMT, and others, we ask ourselves what — if anything — has changed. We argue that the internet has trivialized the costs and challenges of the earlier limiting factors because technology makes it easier 1) for workers to do complex work without training, 2) to manage workers in doing complex work, and 3) to create the infrastructure necessary to manage the workers.

Technology increases non–experts' levels of expertise by giving access to information that would otherwise be unavailable. For example, taxi drivers in London endure rigorous training to pass a test known as "The Knowledge" — a demonstration of the driver's comprehensive familiarity with the city's roads. This test is so challenging that veteran drivers develop significantly larger the regions of the brain associated with spatial functions such as navigation [70, 69, 93, 94, 106, 105]. In contrast, with on–demand platforms such as Uber, services such as Google Maps & Waze make it possible for people entirely unfamiliar with a city to operate profesionally [92, 42]. Other examples include search engines enabling information retrieval, and word processors enabling spelling and grammar checking. By augmentating the human intellect [27], computing has shifted the complexity of work that is possible without training.

Algorithms have automated some tasks that previously fell to management. Computational systems hire workers [67, 103], as well as direct their activities [64], and act as "piecework clerks" [32] to inspect, modify and combine work [47, 74]. In many cases, the intermediary function has been removed as well, leading workers to need to directly email requesters for clarification and feedback [72]. These algorithms, however, are less able than human managers to manage contingencies that were not programmed into them.

Finally, the organizational limit on infrastructure creation is somewhat lessened. Writing web scripts takes fewer people and fewer hours than creating physical equipment for piecework. Little et al.'s vision was that any user with basic programming skills could tap into on–demand human intelligence. As better toolkits lower this threshold [77] and computational thinking diffuses, a broader population will be able to use crowd work.

Implications for crowd work

Technology's ability to support human cognition will enable stronger assumptions about workers' abilities, increasing the complexity of crowd work outcomes. Just as the shift to expert crowdsourcing increased complexity, so too will workers with better tools increase the set of tasks possible. Beyond this, further improvements would most likely come from replicating the success of narrowly–slicing education for expert work as Hart and Roberts and Grier described in their piecework examples of human computation [35] and drastically reformulating macro–tasks given the constraints of piecework [39]. To some extent, an argument can be made that MOOCs and other online education resources provide crowd workers with the resources that they need, but it remains to be seen whether that work will be appropriately valued, let alone properly interpreted by task solicitors [3]. If we can overcome this obstacle, we might be able to empower more crowd workers to do complex work such as engineering and metalworking, rather than doom them to "uneducated" match girl reputations [89]. However, many such experts are already available on platforms such as Upwork, so training may not directly increase the complexity accessible to crowd work unless it makes common expertise more broadly available.

Will the shift from human managers to Turing–complete algorithms raise the complexity ceiling? By the Turing test, the algorithms would be at best indistinguishable from human piecework clerks and foremen. So in terms of enabling coordination, algorithmic management is unlikely to directly raise the ceiling beyond what piecework could achieve. However, as a resource constraint, algorithms are a fixed cost and not a per–person cost like human managers. So in terms of accessibility, algorithms will allow a broader class of organizations and individuals to afford crowd work. This shift may enable complex goals that were not cost–effective before to become feasible. However, because algorithms remain far from replicating all of the foremen's responsibilities, most likely is a middle ground in which crowd work re–introduces the human element to management in a more targeted way (e.g., [37, 57, 104]). This move will require resolving the tension between workers and perilously antagonistic managers, as Boal and Pencavel suggest, to break a toxic cycle of mistrustful requesters [31].

Finally, the cost of creating piecework infrastructure has dropped. Expensive manufacturing equipment has been largely replaced by computer code [65]. As with lowered costs of management, lowered infrastructure costs will make crowd work accessible to a broader set of people and organizations. This in and of itself does not raise the complexity ceiling, but by broadening the potential market for crowd work, it may enable a new set of goals and needs take part.

Decomposing Work

At its core, on–demand work has been enabled by decomposition of large goals into many small tasks. As such, one of the central questions in the literature is how to design these microtasks, and which kinds of tasks are amenable to decomposition. In this section, we place these questions in the context of piecework's Tayloristic evolution.

Crowd work's perspective

Many contributions to the design and engineering of crowd work consist of creative methods for decomposing goals. Even when tasks such as writing and editing cannot be reliably performed by individual workers, researchers demonstrated that decompositions of these tasks into workflows can succeed [54, 9, 96, 78]. These decompositions typically take the form of workflows, which are algorithmic sequences of tasks that manage interdependencies [11]. Workflows often utilize a first sequence of tasks to identify an area of focus (e.g., a paragraph topic [54], an error [9], or a concept [110, 112] and a second sequence of tasks to execute work on that area. This decomposition style has been successfully applied across many areas, including food labeling [79], brainstorming [91, 109], and accessibility [59, 58, 60].

If decomposition is key to success in crowd work, the question arises: what can, and can't, be decomposed? Moreover, how thinly can work be sliced and subdivided into smaller and smaller tasks? The general trend has been that smaller is better, and the microtask paradigm has emerged as the overwhelming favorite [97, 98]. This work illustrates a broader sentiment in both the study and practice of crowd work, that microtasks should be designed resiliently against the variability of workers, preventing a single errant submission from impacting the agenda of the work as a whole fully exploiting the abstracted nature of each piece of work [45, 61, 99]. In this sense, finer decompositions are seen as more robust — both to interruptions and errors [21] — even if they incur a fixed time cost. At the extreme, recent work has attempted demonstrated microtasks that take seconds [100, 16] or even fractions of a second [56]. However, workers perform better when similar tasks are strung together [61], or chained and arranged to maximize the attention threshold of workers [15]. Despite this, we as a community have leaned *into* the peril of low–context work, "embracing error" in crowdsourcing [56].

The general lesson has been that the more micro the task, and the more fine the decomposition, the greater the risk that workers lose context necessary to perform the work well. For example, workers edit adjacent paragraphs in inconsistent ways [9, 52], interpret tasks in different ways [50], and exhibit lower motivation [53] without sufficient context. Research has sought to ameliorate this issue by designing workflows help workers "act with global understanding when each contributor only has access to local views" [101], typically by automatically or manually generating higher–level representations for the workers to reflect on [22, 101, 52].

As the additional context necessary to complete a task diminishes, the invisible labor of *finding* tasks [72] has arisen as a major issue. Chilton et al. illustrate the task search challenges on AMT. Workers seek out good requesters [72] and then "streak" to perform many tasks of that same type [23]. and some work has gone into ameliorating the problems specific to this work site (*ReLauncher*),

Researchers have reacted by designing task recommendation systems [e.g. 25] and others focused on minimizing the amount of time that people need to spend doing anything other than the work for which they are paid [17].

Piecework's perspective

Brown inquired from another direction, asking what limited the adoption of piecework in industries that otherwise gravitated toward it (in the case studies he examined, this mostly focused on railway engineers), ultimately arguing that factors such as the nature of the work design (specifically, the homogeneity of tasks) and the costs associated with adopting a piecework model were the major contributing factors that determined the use of piecework [14].

[al2: This can be trimmed to just reference back to the piecework review] **The research community relating to piecework and labor has been wrestling with the decomposition of work for the better part of a century.** The beginnings of systematic task decomposition stretch back as far as the 19th century, when Airy employed young boys at the Greenwich Observatory who "possessed the basic skills of mathematics, including 'Arithmetic, the use of Logarithms, and Elementary Algebra' " to compute astronomical phenomena [35]. The work that Airy solicited resonates with modern crowd work for several reasons. First, work output was quickly verifiable; Airy could assign variably skilled workers to compute values, and have other workers check their work. Second, tasks were discrete — that is, independent from one another. Third, workers could be trained on a very narrow subset of mathematical skills to be sufficiently qualified to do this work.

Piecework researchers enumerate a number of problems with the decomposition of work, and the conflicting pressures managers and workers put forth. Bewley in particular points out that the approach of paying workers by the piece is "… not practical for workers doing many tasks, because of the cost of establishing the rates and because piecework does not compensate workers for time spent switching tasks". Ultimately, Bewley argues that "[piecework is] infeasible, because … total output is the joint product of varying groups of people" [10].

Comparing the phenomena

Where measurement and instrumentation were limiting factors for historical piecework, computation has changed the situation so that a dream of scientific management and Taylorism — to measure every motion at every point throughout the workday and beyond — is not only doable, but trivial [102]. Where Graves directly implicates measurement as preventing scientific management from being fully utilized, no longer exists modern crowd work is measuring and modeling every click, scroll, and keyboard event [87, 86]. The result is that on–demand work can articulate and track far more carefully than piecework historically could.

A second shift is the relative ease with which the metaphorical "assembly line" can be changed. Historical manufacturing equipment could not quickly be assembled, edited, and redeployed [43]. In contrast, today system–designers can share, modify, and instantiate environments like sites of labor in a few lines of code [65, 67]. This opportunity has spurred an entire body of work investigating the effects of ordering, pacing, interruptions, and other factors in piecework that would have been all but impossible to manipulate as few as 20 years ago [26, 15, 21, 20, 56].

Third, modern crowd work has sliced work to such small scales that the marginal activities — things like finding work and cognitive task switching — have become large relative to the tasks themselves [23]. In the historical case of piecework, moving metallurgical tools, mining equipment, or other industry materials would have been prohibitively difficult and slow; workers were encouraged to specialize in a single set of tasks, allowing pieceworkers to sequence their tasks optimally on their own [39]. The result is that crowd workers are more free agents than historically was the case. However, because they spend significant time searching for tasks, the piece rate is less a good estimate of take–home earnings than before.

Implications for crowd work

If measurement precision limited the depth of decomposition for piecework historically, as Graves argues, then modern on–demand work stands to become far more finely–sliced and highly decomposed than ever before. Online tools make measurement and validation so easy [87] that these aspects of piecework are solved, or near enough that they no longer limit task decomposition. Now, not just tasks, but entire workers' histories [41], can be collected and analyzed in detail.

However, decomposition has hit a second bottleneck: cognition. Task switching costs and other cognitive costs make it difficult to work on tasks so far decontextualized from their original intention [61]. There will of course be tasks that can be decomposed without much context, and these will form the most fine–grained of microtasks. However, other tasks cannot be freed from context — for example, logo design requires a deep understanding of the client and their goals. In part due to this limitation, 99designs workers often recycle old designs rather than make new ones for each client [8].

So, ultimately, the levels of decomposition are likely to follow the contours of context required. Low–context work will be extremely highly decomposed. High–context work will continue to be limited.

The Relationships of Workers to Work, Peers, and Others

HCI and CSCW have framed themselves around supporting work rather than becoming an infrastructural layer enabling it. While all artifacts have politics, this shift into computational labor systems has directly impacted the lives and livelihood of workers. So, it is important to understand: what will the future look like for the workers who use these systems?

Crowd work's perspective

One of the initial questions that researchers asked was, who are the crowd workers and what draws them to crowd work? Early literature emphasized motivations like fun and spare change, but this narrative soon shifted to emphasize that many workers use platforms such as Amazon Mechanical Turk as a primary source of income [51, 44, 7]. Despite this, Mechanical Turk is a low-wage affair for most workers in the United States [44, 72, 36]. Thus, those who choose to opt out of the traditional labor force and spend significant time on Mechanical Turk are especially motivated by the opportunity for autonomy and skill variety [51]. Due to valuing autonomy, it is tempting to ascribe attitudes of "pity the workers" to Turkers, but this frame is increasingly rejected by workers and designers as patronizing [46].

Workers' relationships with requesters are fraught. Workers are often blamed for any low-quality work, regardless of whether they are responsible [72, 74]. Some research is extremely open about this position, blaming unpredictable work on "malicious" workers [31] or those with "a lack of expertise, dedication [or] interest" [90]. Workers resent this position — for good reason. Irani and Silberman highlighted the information asymmetry between workers and requesters on AMT, leading to the creation of *Turkopticon*, a site which allows Turkers to rate and review requesters [47]. Dynamo then took this critique on information asymmetry and power imbalances a step further, designing a platform to facilitate Turkers acting collectively to bring about changes to their circumstances [88]. This unbridled power that requesters have over workers and the resultant stress and frustration that this generates has been part of the undercurrent of research into the tense relationships between workers and requesters [33, 88].

Researchers have also begun to appreciate the sociality of crowd workers. Because the platforms do not typically include social spaces, workers instead congregate off-platform in forums and mailing lists. There, Turkers exchange advice on high-paying work, talk about their earnings, build social connections, and discuss requesters [72]. Many crowd workers know each other through offline and online connections, coordinating behind-the-scenes despite the platforms encouraging independent work [34, 108]. However, the frustration and mistrust that workers experience with requesters does occasionally boil over on the forums. This behavior has come to be known as "mega–drama" amongst such workers [88]. Still, the study of these communities is made challenging because most of these platforms do not themselves include social affordances for workers [76].

Piecework's perspective

Early observers believed that workers were strongly motivated by the piecework model. Clark observed textile mill pieceworkers and reported, "When he works by the day the Italian operative wishes to leave before the whistle blows, but if he works by the piece he will work as many hours as it is possible for him to stand." Workers' situations were quite dire: Riis documented abhorrent working and living conditions of pieceworkers in New York City [84].

Soon, many worker organizations were weighing in on (or, more precisely, against) piecework and the myriad oversights it made in valuing workers' time [49, 83]. As mounting attention increasingly revealed problems in piecework's treatment of workers, the workers themselves began to speak out about their frustration with this new regime. Organizations representing railway workers, mechanical engineers, and others began to mount advocacy in defense of workers [49, 83].

Pieceworkers' relationships with their employers eventually developed a pattern of using laborer advocacy groups [66, 4, 73, 48]. Collective action grew to become a central component of negotiating with managers [38, 80].

Less is known about how pieceworkers related to each other. For one thing, the research methods we typically associate with the exploratory study of cultures — Anthropology, and namely participant–observation, ethnography, etc... — didn't exist quite as we know them at the turn of the 20th century, and wouldn't for several more decades. Primary sources indicate that labor organizations wished for workers to identify as a collective group, "not only as railroad employees but also as members of the larger life of the community" [49]. Doing this, Ostrom and others argued, would facilitate collective action and perhaps collective governance [81, 38, 80]. Riis also contributed to this sense of shared struggle and endurance by documenting pieceworkers in their home–workplaces, literally bringing to light the grim circumstances in which pieceworkers lived and worked [84].

Comparing the phenomena

While historical pieceworkers could be looked down on, as the match-stick girls were characterized by "brashness, irregularity, low morality, and little education", there was generally less written about quality concerns for historical pieceworkers than there is in modern crowd work. Why the difference? One possibility is that, through writing web scripts and applying them to many tasks, it is possible for a small number of spammers have an outsized influence. Historically, it was much harder for such workers to move and get new jobs — today, they can simply accept a different task on Mechanical Turk. Another possibility: online anonymity breeds distrust [29], and where pieceworkers could be directly observed by foremen, online workers are known by little more than an account ID.

The relationship between workers and employers has also shifted: while historically the management of workers had to be done through a foreman (who necessarily had an intuitive — perhaps sympathetic — relationship with workers), the foreman of the 20th century has largely been replaced by algorithms of the 21st century [64]. The result of this change is that the agents managing work are now cold, logical, and unforgiving. Where a person might recognize that the "attention check" questions proposed by Le et al. ensure that malicious and inattentive workers are stopped, some implementations of these approaches only seem to antagonize workers. More than 30 years ago, Anderson and Schmittlein wrote: "When performance is difficult to evaluate, imperfect input measures and a manager's subjective judgment are preferable to defective (simple, observable) output measures" [5]. This frustration has only grown as requesters have had to rely on automatic management mechanisms. Only a few use the equivalent of human foremen [37, 57].

Relative to the mature state of collective action for pieceworkers offline, crowd workers have struggled to make their voices heard [88, 46, 47]. Both pieceworkers and crowd workers have struggled at times to form a collective identity necessary to organize. With workers joining and leaving the crowd labor force continuously, and with many part-time members, it is extremely difficult to corral the group to make a collective decision [88]. However, even when they can: whereas pieceworkers could physically block access to a site of production, online labor markets provide no facilities for workers to change the experience of other workers. This is a key limitation — without it, workers cannot enforce a strike.

Implications for crowd work

The decentralization and anonymization of crowd work will continue to make many of its social relationships a struggle. While some workers get to know each other well on forums [72, 34], many never engage in these social spaces. Without intervention, worker relationships and collectivism are likely to be inhibited by this decentralized design. One option is to build worker centralizing points into the platform, for example asking workers to vote on each others' reputation or allowing groups of workers to collectively reject a task from the platform [104].

The history of piecework further suggests that relationships between workers and employers might be improved if employers engaged in more human management styles. Instead of delegating as many management tasks as possible to an algorithm, it might be possible to build dashboards and other information tools that empower modern crowd work foremen [57]. If the literature on piecework is to be believed, more considerate *human* management may resolve many of the tensions we've discovered among among crowd workers.

Reciprocally, crowd work may be able to inform piecework research. There exists far less literature about pieceworkers' relationships than there does today about crowd workers' relationships. Crowd work research benefits from both the accessibility of digital platforms, as well as the firmer theoretical basis of Anthropology than existed at the turn of the 20th century, when piecework began to emerge. Malinowski, Boas, Mead and Boas and other luminaries throughout the first half of the 20th century effectively defined Cultural Anthropology as we know it today; *participant–observation*, the *etic* and the *emic* understanding of culture, and *reflexivity* didn't take even a resemblance of their contemporary forms until these works [71, 13, 75]. Modern crowd work may give us an opportunity to revisit open questions in piecework with a more refined lens.

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