Principles for Macro Ethics of Sociotechnical Systems: Taxonomy and Future Directions

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The rapid adoption of artificial intelligence (AI) necessitates careful analysis of its ethical implications. In addressing ethics in AI, it is important to examine the whole range of ethically relevant features rather than looking at individual agents alone. Appreciating a wider range of ethical features can be achieved by shifting perspective to the systems in which agents are embedded, which is encapsulated in the macro ethics of sociotechnical systems (STS). Through the lens of macro ethics, the governance of systems — which is where participants try to promote outcomes and norms which reflect their values — is key. However, multiple-user social dilemmas can arise in STS when stakeholders of the STS have different value preferences, or when norms in the STS conflict. Abilities to resolve these dilemmas in satisfactory ways may be aided by the incorporation of normative ethical principles in reasoning. Normative ethical principles are understood as operationalisable rules inferred from philosophical theories. A taxonomy of ethical principles is thus beneficial to enable practitioners to utilise them in reasoning.

This work develops a taxonomy of normative ethical principles which can be operationalised in the governance of STS. We identify an array of ethical principles, with 25 nodes on the taxonomy tree. We describe the ways in which each principle has previously been operationalised, and explain potential difficulties that may arise. We further suggest how the operationalisation of principles may be applied to the macro ethics of STS. We envision this taxonomy will facilitate the development of methodologies to incorporate ethical principles in reasoning capacities for governing equitable STS.

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1 INTRODUCTION

The rapid development of AI systems entails the importance of understanding their ethical impact [23]. In the development of AI, there has been a recent shift in agent (acting entities that perform actions to achieve goals, which are decisions made using AI, [79]) research from emphasis on single agents to multiagent systems (MAS: multiple technical agents deployed into a common environment, [80]). The growing focus on MAS in research necessitates careful analysis of its ethical implications [18, 31]. In pursuing the development of more ethical MAS, shifting perspective to sociotechnical systems (STS) is important as it incorporates the human element in ethical reasoning [76, 87]. In an STS, humans and agents work together as ethical duos, with the agent acting on behalf of their human counterpart. Within the context of an STS, it is also important to adopt the perspective of macro (as opposed to micro) ethics [18]. This is because micro ethics, which focuses on a single agent's decision-making within an STS, may be too narrow to consider the whole

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range of ethically relevant features. Macro ethics thus adopts a wider viewpoint by considering the governance of STS.

Under the perspective of macro ethics of STS, stakeholders govern systems through promoting certain outcomes and norms (rules of expected behaviour, [74]) that align with their values (what is important to us in life, [88]). Appreciating the incorporation of norms and values in governance of STS is key, because ethics should be understood as a reflective development process that incorporates context [57, 67, 73, 102]. Values are an important aspect of context [65] as they reflect stakeholder preferences [3, 32]. Norms are also important to context as they can help ensure systems behave consistently with human values [72, 76, 90]. This is because norms can be utilised in agent societies to encourage participating agents to behave in acceptable ways [74]. Values and norms are thus pivotal for ethical reasoning [2, 30, 91, 100] and key features of STS from the perspective of macro ethics.

However, users (here, users are synonymous with stakeholders) may have different value preferences or their values may conflict with norms [24]. Challenges thus arise in making decisions concerning multiple users [56, 61]. These scenarios are known as multiple-user social dilemmas and can occur in mundane settings. An example of such a mundane setting may be a smart home agent deciding when to put the heating on, taking into account the preferences of existing users and other contextual features. A dilemma may arise if stakeholders have different value preferences, such as some valuing comfort (thus implying the heating should be turned on) and others value saving money (thus implying the heating should be turned off).

Resolving these dilemmas in satisfactory ways with an overarching goal of fairness may be aided by the incorporation of normative ethical principles in reasoning [99]. Normative ethics is the study of practical means to determine the ethicality of an action through the use of principles and guidelines, or the rational and systematic study of the standards of right and wrong [76]. Ethical principles imply certain logical propositions that must be true in order for a given action plan to be ethical [54]. Therefore, the application of ethical principles may be useful in order to methodically think through dilemmas and promote satisfactory outcomes [21]. Such principles can help to guide normative judgements, understand different perspectives, and determine the moral permissibility of concrete courses of actions [16, 64, 69, 86].

Normative ethical principles have previously been utilised for a variety of different applications in computer science. For binary machine learning algorithms, works such as Binns [11] and Leben [59] apply ethical principles to improve fairness considerations. In the decision making of agents, Cointe et al. [20] implement ethical principles to enable agents to make ethical judgements in specific contexts. Ethical principles can also be applied to improve fairness considerations in systematic analysis [21, 86]. By examining how literature has operationalised such principles, it may be possible to implement normative ethical theories in the governance of STS. This could contribute to satisfactory resolution of multiple-user social dilemmas, in which values and norms conflict. As ethical thinking needs to be fostered through the appreciation of a variety of different approaches, considering the strengths and limitations of each [15, 83], we envision that a taxonomy of ethical principles, including how they have previously been operationalised, will contribute to the overall aim of improving fairness in the governance of STS.

1.1 Motivation for a Taxonomy of Ethical Principles

The motivation for this work therefore stems from the need to improve ethical considerations in STS. Operationalising normative ethical principles in the governance of STS may help to address these concerns [99]. Ethical principles imply certain logical propositions that must be true in order for a given action plan to be ethical [54]. Therefore, the application of ethical principles may be useful in order to methodically think through dilemmas and promote satisfactory outcomes [21].

Such principles can help to guide normative judgements, understand different perspectives, and determine the moral permissibility of concrete courses of actions [16, 64, 69, 86]. Ethical thinking needs to be fostered through the appreciation of a variety of different approaches, considering the strengths and limitations of each [15, 83]. We thus envision that a taxonomy of ethical principles will aid this ethical thinking.

1.2 Gaps in Related Research

In the context of AI ethics, there are two types of principles referred to: (1) those inferred from normative ethics such as Deontology and Consequentialism, as found in Leben [59], and (2) those adapted from other disciplines like medicine and bioethics such as those suggested by Floridi and Cowls [39], Jobin et al. [48], Fjeld et al. [37], and Cheng et al. [17] including beneficence, non-maleficence, autonomy, justice, fairness, non-discrimination, transparency, responsibility, privacy, accountability, safety and security, explainability, human control of technology, and promotion of human values.

To ensure clarity of terminology, we refer to principles from normative ethics as *ethical principles*, and those as highlighted by Floridi and Cowls [39] and Jobin et al. [48] as *AI keystones*. Ethical principles as defined here are thus established philosophical theories which can be operationalised in reasoning capacities, as they imply certain logical propositions which must be true in order for a given action plan to be ethical, Kim et al. [54] purport. C8 These principles broadly divide into Deontological principles (those which entail conforming to rules, laws, and norms Hagendorff et al. [44] explain) and Teleological principles (those which derive duty or moral obligation from what is good or desirable as an end to be achieved, Britannica [14] discuss). AI Keystones, on the other hand, are more general themes that an ethical principle may aim for in its application. To illustrate the distinction, the principle of Egalitarianism, for example, supports the notion that human beings are in some fundamental sense equal, as explained by Binns [11]. To work towards the AI Keystone of fairness, Egalitarianism may be operationalised by increasing efforts to avoid inequality. This could take the form of a rule that opportunities must be equally open to all applicants, Lee et al. [60] suggests.

AI Keystones Themes such as beneficence, non-maleficence, autonomy, justice, fairness, non-discrimination, transparency, responsibility, privacy, accountability, safety and security, explainability, human control of technology, and promotion of human values that should underpin the design of AI technologies.

Ethical Principles Operationalisable rules inferred from philosophical theories such as Deontology and Consequentialism.

Existing taxonomies and surveys are present in the relevant but distinct domain of AI keystones such as Jobin et al. [48], Floridi and Cowls [39] and Khan et al. [53], however, not in ethical principles as is defined here. The work of Tolmeijer et al. [96] contains an overview of implementations of machine ethics, providing useful guidance as to the technical and non-technical aspects of implementing ethics and evaluating systems. However, the authors do not capture the whole range of ethical principles we capture. In addition, Tolmeijer et al. consider the larger scope of machine ethics, rather than AI ethics and MAS, as we aim to address. Similarly, Yu et al. [101] identify a high-level overview of ethical principles, but fail to recognize the extent that has been found in our work, and do not consider them in the same level of depth. Dignum [29], Leben [59], and Robbins and Wallace [83] give summaries of normative ethics, however, to enable broader applicability, these works may benefit from a formal taxonomy including other ethical principles seen in computer science.

1.3 Organisation

Section 2 explains the methodology in brief. This may be useful for future research seeking to expand the taxonomy of ethical principles by reproducing the methods used here. Section 3 explores our findings from the objective Q_p, as to the ethical principles that have been so far proposed in Computer Science literature. Section 4 examines objective Q_o, looking at how ethical principles have been operationalised before, and what steps practitioners seeking to operationalise principles should to take. Section 6 focuses on objective Q_g, explaining gaps we identified in operationalising ethical principles in Computer Science and Artificial Intelligence. Section 7 concludes with our key takeaways.

2 METHODOLOGY IN BRIEF FOR REPRODUCIBILITY

Taking inspiration from software engineering research, such as Lo et al. [66], for reproducibility and extendability of the taxonomy, we follow Kitchenham's [55] guidelines on conducting a systematic literature review to develop our taxonomy for ethical principles.

2.1 Objective

Our broad objective is to investigate the current understanding of ethical principles in AI and computer science and how these principles are operationalised. Specifically, we address the following questions:

Q_p (Principles). What ethical principles have been so far proposed in computer science literature? The purpose of this question is to aid the identification of principles currently used in literature within the domain of AI and computer science. Due to the intricacies of philosophical discourse, we follow the approach of Tolmeijer et al. [96] in providing brief overviews of how each principle has been defined in literature, rather than attempting to give an introduction to moral philosophy.

Q_o (Operationalisation). How have ethical principles been operationalised in AI and computer science research?
This question looks at the identified principles to examine how they have been operationalised in AI and computer science. Works such as Leben [59] and Tolmeijer et al. [96] give some guidance as to how certain ethical principles may be operationalised, however, they miss some principles.

Q_g (Gaps). What are existing gaps in ethics research in AI and computer science, specifically in relation to operationalising principles in STS?
This question aids analysis of the gaps that exist in operationalising the principles within the scope of STS to direct future research.

2.2 Sources Selection and Strategy

After defining our objective and questions, we formed the strategy to search for primary studies by identifying keywords and resources. We select Google Scholar and the University of Bristol Online Library as resources to search. They are both large databases with links to a wide variety of other sources of research with published papers on the topic. We searched the selected resources using various combinations of the chosen keywords, which can be found in Section 2.2.1.

We first inspected up to the first 5 pages of results in each resource, and then narrowed the search by applying the inclusion and exclusion criteria to the titles. This specified the search to a smaller selection of works of whose abstracts were read. The inclusion and exclusion criteria were then more closely applied, leading to the identification of the primary studies. From the research works gathered in this initial search, relevant citations that met the criteria were followed to expand the search, which allowed material to be collected from a broader array of origins.

Figure 1 outlines our method in brief.

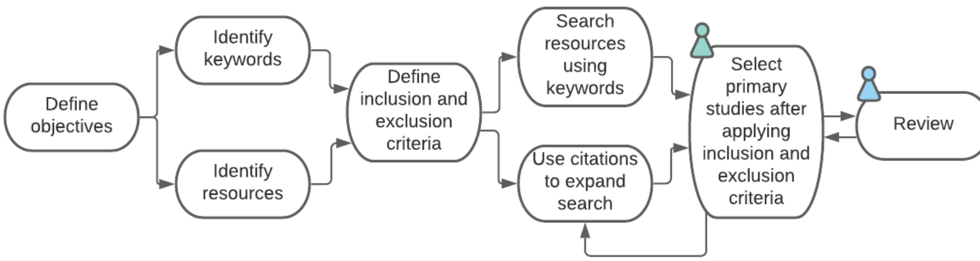

Fig. 1. Method in brief

2.2.1 Search String Definition. Our search string contained two main components. The first component related to AI and various related terms, whereas the second component related to normative ethics. The search string used was (‘AI’ OR ‘Agent’ OR ‘ML’ OR ‘Multiple-User’ OR ‘Multiagent’) AND (‘Consequentialism’ OR ‘Deontology’ OR ‘Egalitarianism’ OR ‘Equality’ OR ‘Ethics’ OR ‘Utilitarianism’).

2.2.2 Inclusion and Exclusion Criteria. First, work is included from a series of well-known journals and conferences identified from literature found in the initial searches. Specifically including these resources ensures topical works are included, however it also opens up the threat that resources not on the list may be missed. We mitigate risk by following relevant citations from primary studies to expand the scope, however acknowledge that time limitations remain. We exclude works about meta-ethics (e.g. the meaning of moral judgement) and applied ethics outside of computer science (e.g. biology ethics).

Second, we include works related to individual or group fairness. We exclude works about fairness in specific ML methodology, as that is outside the scope of this project. Third, we include works related to multiple-user social dilemmas in order to examine how ethical principles are operationalised in these settings. We exclude studies about how ethical principles affect other non-social dilemmas. Fourth, we include the intersection of normative ethics and multiple-user AI or MAS research, whereas we exclude non-ethical studies (e.g. about technical implementation) in this area. Fifth, we include studies about normative ethical principles and AI, but we exclude studies solely about AI keystones. This is because, whilst AI keystones contain important information about ethical implementation, it is out of the scope of this review. Sixth, we include studies about bias when related to ethical principles, as this is relevant to how ethical principles affect fairness, however we exclude studies about bias that do not talk about ethical principles.

2.3 Relevant Works

We conducted an initial search on 01-Jun-21. The search produced 3.74 million results on Google Scholar and 998,613 results on the University of Bristol Online Library. Looking at the first 5 pages of results, we applied the inclusion and exclusion criteria, which lead to around 10–20 studies from each resource. Closer examination of these works lead to the identification of relevant citations and which we incorporated into our review. The selection of these works was critiqued by a secondary researcher which helped the identification of further relevant research. This resulted in 56 papers being included in the review. We conducted a second search on 23-May-22, resulting in a further 7 papers being included in the review.

Table 1. Categorisation of Research Reviewed with Principles Extracted: Frameworks

Topic \ Type	Frameworks (Conceptualization)	Frameworks (Application)	Algorithms	Viewpoint or Review
Deontology	[1, 11, 13, 20, 43, 59, 76, 86, 98]	[6, 9, 10, 25, 46, 62, 64, 83]	[46, 84]	[44, 52, 96, 101]
Egalitarianism	[9, 11, 19, 34, 38, 40, 59, 75, 82, 89]	[33]	–	[60]
Proportionalism	[35, 50, 59]	[33]	–	–
Kantian	[1, 4, 45, 51, 54, 98]	[10, 62, 83, 95]	[84]	[58, 96]
Virtue	[1, 5, 13, 20, 43, 45, 46, 76, 86, 98]	[42, 46, 83]	[46, 84]	[44, 52, 96, 97, 101]
Consequentialism	[1, 13, 20, 22, 43, 45, 59, 86, 92, 93]	[9, 10, 62]	[84]	[36, 96, 101]
Utilitarianism	[1, 4, 5, 9, 13, 46, 54, 59, 70, 75, 76, 98]	[2, 7, 10, 25, 62, 64, 83, 95]	[46, 84, 90]	[36, 52, 58, 101]
Maximin	[59, 81]	[2, 10]	[28, 94]	[60]
Envy-Freeness	[12]	–	[94]	[60]
Doctrine of Double Effect	–	[10, 41, 64, 71]	–	[26]
Doctrine of Disparate Impact	[11]	–	[78]	–
Do No Harm	[27]	[64]	–	–

3 TAXONOMY OF ETHICAL PRINCIPLES

To address Q_p (Principles), research on AI and ethical principles is broadly categorised into twelve key principles, based on their definition of normative ethics (Deontology, Egalitarianism, Proportionalism, Kantian, Virtue, Consequentialism, Utilitarianism, Maximin, Envy-Freeness, Doctrine of Double Effect, Doctrine of Disparate Impact, and Do No Harm), and five types of study (Frameworks (Conceptualisation), Frameworks (Application), Algorithms, and Viewpoint or Review), based on the structure and contributions of the paper. This is displayed in Table 1.

In terms of the paper structure, we found that the large majority of works focused on conceptual frameworks which proposed theoretical ideas as to how the principles might be operationalised, such as Leben [59] and Wallach et al. [98]. Some papers computationally applied such frameworks, for example Limarga et al. [62] and Linder et al. [64]. A few papers proposed algorithms mechanising ethical principles, such as Sun et al. [94] and Diana et al. [28]. Lastly, we found that there were also viewpoint or review papers scoping related areas, such as Yu et al. [101] and Lee et al. [60].

Regarding normative ethical principles, there are two main strands of theory: Deontology and Teleology. Deontological theories revolve around rules, rights, and duties [76, 98]. Teleological ethics, on the other hand, derive duty or moral obligation from what is good or desirable as an end to be achieved, [14]. Teleological ethics can be further divided into Consequentialism, Egoism, and Virtue Ethics. Figure 2 displays the taxonomy of principles identified in literature in a tree structure, mapping out how they relate to each other.

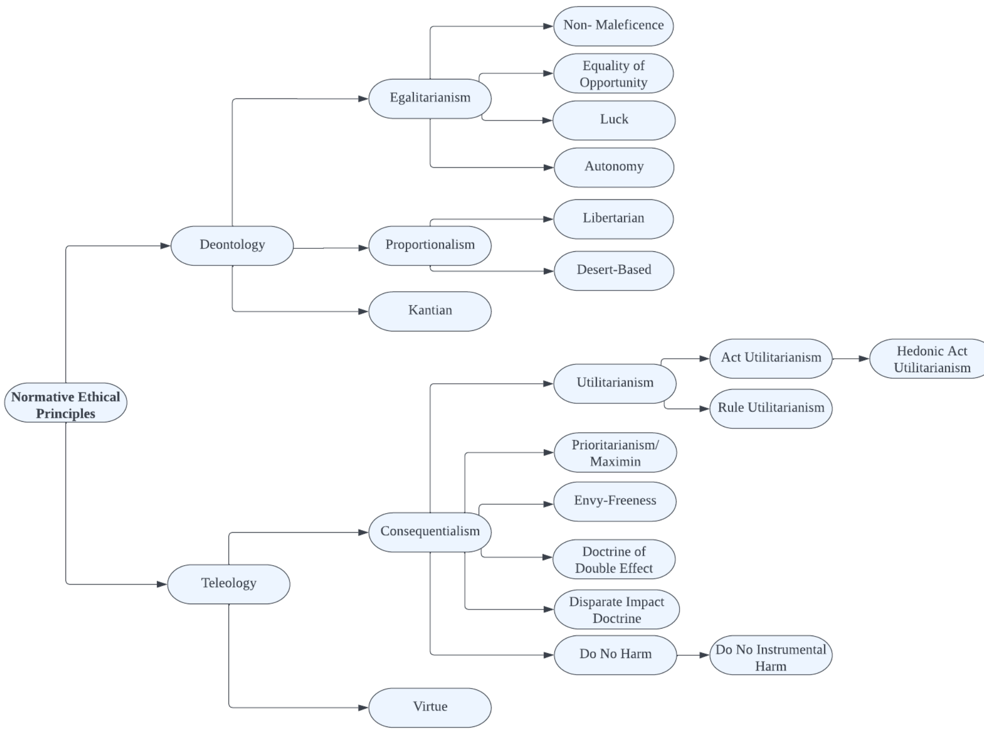

Fig. 2. Taxonomy of Ethical Principles

We find that certain principles, such as Utilitarianism, were much more discussed than other principles such as Do No Harm, as can be seen in Table 1. We also find that there is a significant amount of research referencing 'Deontology' and 'Consequentialism' as broad terms, but not specifying what types of Deontology or Consequentialism they are referring to, for example Cointe et al. [20], Greene et al. [43], and Anderson and Anderson [6]. These works would perhaps benefit by more clearly specifying the ethical principles they are using, in order to allow for more precise operationalisation.

3.1 Deontology

Deontology entails conforming to rules, laws, and norms [44, 76], and respecting relevant obligations and permissions [20] that stem from duties and rights [4, 52, 83, 84, 86, 96, 98, 101]. For Deontological theories, the permissibility of action lies within the intrinsic character of the act itself. An action is permissible if and only if the act itself is intrinsically morally good, independent of the outcome [13, 62, 64]. To implement Deontological theories, a rules-based approach may be used to identify appropriate actions: Limarga et al. [62] use predicates to encode rules, and then reason about different types of actions; Berreby et al. [10] first collect contextual information to simulate the outcome of actions, and then assess the ethical considerations of that outcome using Deontological specifications; Tolmeijer et al. [96] argue that Deontology could be implemented by inputting the action (in terms of mental states and consequences), using rules and duties as the decision criteria, and then mechanising actions via the extent to which they fit with the rule.

It is also worth considering the different contexts for which Deontology has been applied to. Binns [11] uses Deontology to choose between incompatible fairness metrics, whereas Leben [59] applies it to evaluate distributions of binary classification algorithms. Some also suggest using Deontology only in specific circumstances: Dehghani et al. [25] choose to implement Deontology in situations with 'sacred values', using it to select the choice of action that doesn't violate the sacred value.

However, there are issues that may arise when applying Deontology. One common concern is that because Deontological approaches focus on the intrinsic nature of an action, they fail to take the most likely consequences into account. This makes it challenging for logic to adequately capture complex ethical insights [1, 86]. Also, rights-based ethics revolve around decisions based on the rights of those who are affected by the decision, but this can be less helpful in situations where rights are not impinged yet some sort of ethical dilemma is still occurring. In terms of implementation, there may be issues that arise when exceptions to the rule emerge. Rules are expected to be strictly followed, implying that for every exception they must be amended which may make them rather long. Determining the right level of detail is thus important to ensure interpretability for the machine [96]. Lastly, there may be conflicts between rules. Conflicts may be addressed by ordering or weighing the rules, but this gives rise to difficulties with determining the order of importance.

3.1.1 Egalitarianism. Egalitarianism stems from the notion that human beings are in some fundamental sense equal; efforts should thus be made to avoid and correct certain forms of inequality [11]. Literature implements Egalitarianism by promoting equality in different ways: Murukannaiah et al. [75] suggest minimising disparity across stakeholders with respect to satisfying their preferences; Dwork et al. [33] classify individuals who are similar with respect to a particular attribute similarly; Leben [59] confers equal rights (and thus equal shares) to each member of the population. However, if it is impossible to achieve equality across all metrics for the entire population, they suggest a distribution that minimises the distance to some fairness standard (e.g. size of population). An application of Egalitarianism proposed by Lee et al. [60] is to evaluate various algorithmic fairness metrics, such as positive predictive parity or equal odds. This may help model developers decide what layers of inequality should (not) be influencing the model's prediction.

Certain difficulties are important to acknowledge when considering Egalitarianism. For instance, there is a prominent debate as to whether a single Egalitarian calculus should be applied across different social contexts, or if there are internal 'spheres of justice' in which different fairness metrics may apply, between which redistributions might not be appropriate [11]. Particular measures of Egalitarianism might apply differently to different contexts, for example, universally enforcing a test before being allowed to vote for a political election may lead to people from lower socioeconomic background being excluded from democracy. However, having tests for a job position may seem appropriate if everyone has equal opportunity to take the test, as talents and abilities vary between individuals. One should thus carefully evaluate the metrics being used to impose Egalitarianism. For subtypes of Egalitarianism, see Table 2.

3.1.2 Proportionalism. Proportionalism infers adjusting the rights of each person proportionally based on their contributions to production. Contributions could include the resources from each member of the population that went into production, the amount of actual work that went into the deployment of those resources, and the amount of luck that went into those resources. Leben [59] operationalises Proportionalism by constructing utility functions which evaluate the distribution of rights in accordance with contribution. A fairness standard establishes the ideal distribution of rights by dividing the total amount of contribution by the amount of each individual's contribution.

Table 2. Subtypes of Egalitarianism

Principle	Description	Difficulties
Non-Maleficence	Imposes Egalitarianism across harms but not benefits [59].	Allows for arbitrarily large inequalities in outcomes, and assumes a dubious distinction between 'better-off' and 'worse-off' [59]. It thus is difficult to define what a harm is and what a benefit is.
Equality of Opportunity	Negative attributes due to an individual's circumstances of birth or random choice should not be held against them, yet individuals should be still held accountable for their own actions [33, 40]. One could examine whether each group is equally likely to be predicted a desirable outcome given the base rates for that group [11], or ensure all opportunities should be equally open to all applicants based on a relevant definition of merit [60].	In theory, this can be fully satisfied even if only a minority segment of the population has realistic prospects of accessing the opportunity [38].
Luck	Eliminating unchosen inequalities; no-one should end up worse off due to bad luck, but instead people should be given differentiated economic benefits as a result of their own choices [34, 60].	It is often difficult to define what is within an individual's genuine control [11]. The ideal solution would allow inequalities resulting from people's free choices and informed risk-taking, disregarding those which are the result of brute luck.
Autonomy	Equality of Autonomy has been proposed as including the full range of individual freedom [60]. There must be a minimum level of autonomy, variety and quality of options, and decision-making competence [38].	However, when there is a significant asymmetry of power and information, autonomy in rational decision-makers fails as an ethical objective [38].

The best distribution is thus that which has the minimum distance from this fairness standard for all individuals.

A challenge with Proportionalism is that there may be situations in which groups or individuals did not confer contributions to production, but should still be granted a distribution of rights. For example, a group that are unable to contribute due to disability should still have a fair distribution of rights. However, this may be mitigated by consideration of the influence of luck. For subtypes of Proportionalism, see Table 3.

3.1.3 Kantian. Kantian [51] ethics argues that ethical principles are derived from the logical structure of action, beginning with distinguishing free action (behaviour for which the agent has reasons) from mere behaviour [54]. Kant's *Categorical Imperative* grounds all moral duties [98], as it applies unconditionally to rational agents (categorical), and is a command that could be followed, but might not be (imperative) [49]. The Categorical Imperative thus entails that a rational agent must believe their reasons for acting are consistent with the assumption that all rational agents to whom the reasons apply could engage in the same actions (also known as the *Universal Law of Nature*) [1, 58, 83]. For example, "do not kill" is a Categorical Imperative: it is categorical in that if all rational agents killed, there would be no rational agents left; it is an imperative as rational agents have the ability to kill but should not. Derived from the Categorical Imperative is the *Means-End*

Table 3. Subtypes of Proportionalism

Principle	Description	Difficulties
Libertarian	Libertarianism emphasises the importance of each person's freedom, insofar as there is no harm to anyone else [60]. Rights are distributed accordingly with each person's total contribution at the time of consent. Each group is entitled to success rates at least as fair as initial contributions [59].	A difficulty with this approach lies in that it does not target pre-existing inequalities which may still be worth mitigating. For example, some people may be inhibited from contributing as much as others due to factors outside of their control such as generational wealth inequality. On the other hand, people born into wealthy circumstances due to luck would be rewarded more rights according to this approach, which may seem unfair.
Desert-Based	Contribution is defined in terms of individual effort, discounting the effects of luck, and rights are distributed accordingly. This is because prior prevalence of a trait in a population can be the result of unjust circumstances [59]. This could be implemented by assigning each individual some distance in a metric space that evaluates desert, and then evaluating the fairness of the model through the average distance between individuals from each group in the metric space [33].	A weakness of this principle is that luck is an abstract concept which is difficult to define, and may vary between contexts. This therefore makes evaluating which traits should be mitigated for challenging.

Principle (also known as the *Humanity Formula*). This denotes that treating other people as a means to an end is immoral [1, 58]. It would never be possible to universalise the treatment of another as a means to some end; doing so would contradict the Categorical Imperative. This is because of our ability to engage in rational self-directed behaviour.

This principle has been operationalised in previous literature through the imposition of rules. Limarga et al. [62] implement the Categorical Imperative through the imposition of two rules: firstly, since it is universal, an agent, in adopting a principle to follow (or judging an action to be its duty), must simulate a world in which everybody abides by that principle and consider that world ideal. Secondly, since actions are inherently morally permissible, forbidden, or obligatory, an agent must perform its duty purely because it is one's duty, and not as a means of achieving an end or by employing another human as a means to an end. Berreby et al. [10] implement the Means-End Principle in the rule that an action is impermissible if it involves and impacts at least one person, but that impact is not the aim of the action. Svegliato et al. [95] decouple moral principles (in the form of rules) from the decision making module; for Kantianism they use the moral rule that policies should be universalisable to stakeholders without contradiction. Allen et al. [4] suggest that the Categorical Imperative could be implemented as a higher principle to evaluate other rules. For example, when deciding whether to apply Egalitarianism (ensuring equal distribution), an agent could evaluate if this is the right thing to do by examining if it aligns with the Categorical Imperative; if it would be rational for all agents to apply that principle.

A difficulty with the Categorical Imperative is that it may be too permissive; it could permit intuitively bad things by allowing any action that can have a universalizable maxim [1]. A common example of this is letting a murder into your house because you cannot lie, and say that the person they want to kill is not there. The Means-End principle can also be too stringent, as interpreted strictly, it forbids any action in which a person affects another without their explicit consent.

3.2 Teleological Ethical Principles

This section examines each Teleological principle (morality is derived from what is good or desirable as an end to be achieved [14]) identified in the review, including details as to how they have been previously operationalised and difficulties that may arise.

3.2.1 Virtue Ethics. According to Virtue Ethics, ethicality stems from the inherent character of an individual, and not the rightness or wrongness of individual acts [1, 13, 52, 76, 83, 98, 101]. Right action is performed by someone with virtuous character. In following this theory, one should not be asking what one ought to do, but rather what sort of person one should be [1, 5, 84, 86]. The qualities one possesses should be of primary importance, and actions secondary. Moral virtues can be learnt and developed through habit and practice. The stability of virtues (if one has a virtue, one can't behave as if one doesn't have it) entails that Virtue Ethics may be a useful way of imbuing machines with ethics [98].

There are a variety of different ways in which Virtue Ethics has been implemented in literature. Robbins and Wallace [83] argue that to operationalise this principle, problems are solved ethically through the application of 'virtuous' characteristics. This may be done by targeting the designers of systems, and helping designers develop virtues through education, as suggested by Vanhé and Borit [97]. Other works focus on implementing virtues directly into machines; according to Tolmeijer et al. [96], inputs for implementing Virtue Ethics in machines would be properties of the agent, the decision criteria would be based on virtues, and this would be mechanised through the instantiation of virtues. This is exemplified in Govindarajulu et al. [41] who define that virtues are learnt by experiencing the emotion of admiration when observing virtuous people, and then copying the traits of those people. The authors instantiate this by using computational formal logic to formalise emotions (in particular the emotion of admiration), represent (virtuous) traits, and establish a process of learning traits. Greene et al. [43] argue that a virtue based system would have to appreciate the entire variety of features in a given situation that would call for one action rather than another. Virtue Ethics can also be used alongside other approaches; Hagendorff [44] argue that Deontological approaches should be combined with Virtue Ethics, through looking at values and character dispositions.

A problem with Virtue Ethics is that the holistic view it takes makes it more difficult to apply to individual situations [86]. Further challenges relate to conflicting virtues, and concretion of virtues [96]. To judge whether a machine or human as virtuous is not possible by just observing one action or a series of actions that seem to imply the virtue – the reasons behind them need to be clear. This therefore makes it difficult to build virtues into machines, as there is a high level of abstraction to what virtues actually are. Additionally, the conception of virtues can change greatly across time and culture. Virtues instantiated in machines now may lead to unfair outcomes in the future as virtues change.

3.2.2 Consequentialism. In Consequentialist approaches, right actions are identified through their effects [13, 20, 59, 101]. The moral validity of an action can thus be judged only by taking its consequences into consideration [62, 84, 86]. A strength of this is that it can be used to evaluate decisions with complex outcomes where some benefit and some are harmed, by examining how these benefits and harms are distributed. It can thus explain many moral intuitions that trouble Deontological theories, as Consequentialists can say that the best outcome is the one in which the benefits outweigh the costs [92].

Consequentialist principles can thus be operationalised by analysing the consequences of different actions. This is different to Deontology, which regards ‘mental states’ as very important for determining the ethicality of an action, but for Consequentialism can be largely disregarded, Tolmeijer et al. [96] argue. Conesequentialism is implemented by Limarga et al. [62], who assign each action a weight according to its worst consequence. Actions are part of a sequence of actions to reach a goal, and their weights accumulate to a total value. This value is then optimised to select the sequence with the best overall consequence. Suikkanen [93] similarly suggests ranking agents’ options in terms of how much aggregate value their consequences have. An option is right if and only if there are no other options with higher evaluative ranking. Tolmeijer et al. [96] argue that input for Consequentialist principles would be the action (and its consequences), and the decision criteria would be the comparative well-being. This would then be mechanised by selecting the consequence with maximum utility. For binary classification algorithms, Leben [59] suggests implementing Consequentialism by looking at how weights are assigned to each group outcome based on relative social cost.

However, in practice, assigning weights to each outcome may be unrealistic to do for all outcomes [59]. There might be high computational costs because Consequentialist systems would require a machine to represent all of the actions available to it [43]. A related issue addressed lies in difficulties in estimating long-term or uncertain consequences and determining for whom consequences should be taken into account [36, 86]. There may also be moral constraints outside Consequentialism which prohibit certain actions even when they have the best outcomes, therefore rendering Consequentialist theories incomplete [93]. Another common criticism of Consequentialism concerns deciding what is valuable or intrinsically good: whether it is pleasure, preference-satisfaction, perfection of one’s essential capacities, or some list of disparate objective goods (e.g. knowledge, beauty, etc.) [13, 96]. For subtypes of Consequentialism, see Table 4.

Table 4. Subtypes of Consequentialism.

Principle	Description	Difficulties
Utilitarianism	Something is ethical if and only if it maximizes the total net expected utility across all who are affected [52, 54, 58, 64, 76, 84, 98]. The ultimate end is an existence exempt as far from pain and as rich in enjoyments as possible [4, 70]. Agents could thus be trained to make judgements that deliver the greatest happiness to the greatest number of people [58], e.g. by assigning a value to every action which is used for final evaluation [62]; selecting the choice with the highest utility [9, 25]. An alternative approach decouples the moral principle from the decision module, having a separate moral rule that evaluates the suggested policy [95]. To choose norms in accordance with how much they align with moral values, a recursive utility function could identify the preference utility of each value. The value support of a norm is then calculated by adding the utility of each value that norm is supported by. This arguably enforces Utilitarianism by ensuring norms that promote the most utility are chosen, where utility is understood as (value) preference satisfaction [90]. To justify design choices for fairness metrics in binary classification algorithms, a function could model each potential distribution and its effects (a utility function/measure of happiness outcomes), and then run a selection procedure over aggregate utilities to maximise the sum [59].	This could lead to a minority being treated unfairly for the greater good [2, 7]. It may be impossible to calculate the utility of every action, and the theory cannot account for the notion of rights and duties [1]. It is also difficult to quantify utility [36]. To mitigate these issues, Utilitarianism could be an additional necessary condition for an ethical action, rather than the sole ethical principle [54].
(Hedonic) Act Utilitarianism	Focuses on the morality of an action through its consequences [10, 96]; Hedonic Act Utilitarianism entails computing the best action which derives the greatest net pleasure [13]. A machine utilising this could weigh actions corresponding to their consequences, and then order them accordingly; an action is less desirable if there is another action whose weight is greater [10]. Alternatively, one could input the number of people affected, and for each person the intensity of pleasure/displeasure for each possible action. The algorithm then computes the product of intensity, the duration, and the probability to obtain the net pleasure for each person. This computation is performed for each alternative action [7].	A criticism of Hedonic Act Utilitarianism is that it is difficult to define pleasure; what is pleasurable for one person may not be pleasurable for another. This makes it difficult to identify the action with the greatest net pleasure.

Principle	Description	Difficulties
Rule Utilitarianism	Morally assessing an action by first appraising moral rules on the basis of the principle of utility – deciding whether a (set of) moral rule(s) will lead to the best overall consequences, assuming all/most agents follow it. This could be implemented using a predicate which compounds all effective weights of the actions belonging to a particular rule, then summing up those weights via a predicate [10].	Sometimes a rule may lead to unintuitive outcomes, and therefore should be broken. This makes Rule Utilitarianism look more like Act Utilitarianism, where the right thing to do is evaluated through the consequences of each action.
Prioritarianism/Maximin	Maximising the minimum utility by seeking to improve the worst-case experience in a society [60, 81], e.g. an agent that aims to improve the minimum experience/worst-case outcome for any user [2]. For choices of fairness metrics for binary classification algorithms, a function modelling each potential distribution and its effects could be constructed, then a selection procedure run over aggregate utilities [59]. Fairness could be measured by worst-case outcomes across all groups, rather than differences between group outcomes [28], or by minimising the maximum cost of an allocation over all allocations [94].	Although the aggregate utility may be increased, it does not necessarily mitigate the effects of discrimination [94]. It still allows for disparities between groups. Therefore, the most privileged group may still remain much more privileged than the least privileged group, despite the overall experience being improved.
Envy-Freeness	In an Envy-Free allocation, no agent envies another agent [94]. Fairness thus exists when there are minimal levels of envy between groups or individuals. Resources may be unequally distributed, but as long as agents do not envy one another, this is considered fair [12].	Arguably, what is important might not be a relative condition to other people, but if people have enough to have satisfactory life prospects [60]. Also, the existence of an Envy-Free allocation can't be guaranteed when items are indivisible, e.g. chores that need to be assigned to multiple agents [94].
Doctrine of Double Effect	Deliberately inflicting harm is wrong, even if it leads to good [26, 71]. An action is permissible if the action itself is morally good/neutral, some positive consequence is intended, no negative consequence is a means to the goal, and the positive consequences sufficiently outweigh the negative ones [10, 41, 64].	An issue with the Doctrine of Double Effect is that it still allows bad actions to happen as long as they are not intended, which may have some morally dubious outcomes.
Disparate Impact Doctrine	For group fairness, any group must have approximately equal or proportional representation in the solution provided by the algorithm [78]. The concept of 'disparate mistreatment' has also been suggested, which considers differences in false positive rates between groups [11]. It thus emphasises the importance of ensuring impact is proportionally distributed amongst the relevant groups.	This is may lead to individuals being unfairly treated in favour of the group.
Do No (Instrumental) Harm	No harm should be inflicted, thus any action that causes harm would be unethical [27, 64]. Do No Instrumental Harm allows for harm as a side effect, but not as a means to a goal.	Sometimes, however, there may be situations in which causing harm is inevitable. In such situations, this principle alone would not be able to give clear ethical guidance.

3.3 Other Principles

In addition to the principles mapped out here, there are other principles mentioned in literature. These have not been included in the taxonomy for a variety of reasons, as shall be explained here.

3.3.1 Egoism. Egoism is acting to reach the greatest outcome possible for one's self, irrespective to others [58, 83]. This principle was rarely mentioned in literature and this may be because it would lead to likely unethical outcomes if it was imbued in AI agents. If agents were primarily concerned with themselves, irrespective of others, it seems unlikely that fairness would be an ethical goal for them. This is because fairness is aimed at the well-being of others as well as the self, whereas egoism is solely self-centred.

3.3.2 Particularism. Particularism emphasises that there is no unique source of normative value, nor is there a single, universally applicable procedure for moral assessment [96]. Rules or precedents can guide evaluative practices, however they are deemed too crude to do justice to many individual situations. Therefore, whether a certain feature is morally relevant or not and what role it plays will be sensitive to other features of the situation and ethical evaluation should thus be carried out on a case-by-case basis. Inputs for Particularism could include the situation (context, features, intentions, and consequences), with the decision criteria resting on rules of thumb and precedent, as all situations are unique. The mechanism to decide upon an action would depend on how much it fits with rules or precedent. Some challenges identified are that there are no unique and universal logic, thus each situation needs a unique assessment. The lack of a universal logic for it is part of the reason for not including it in this taxonomy: it does not give clear guidance. However, Particularism is perhaps relevant to the ways in which ethical principles can be operationalised, as it emphasises the inclusion of context in the moral reasoning process. It is not in itself an operationalisable ethical principle, but perhaps more of a meta-principle that can be used in the application of other ethical principles.

3.3.3 The Ethic of Care and Responsibility. The ethic of care and responsibility relates to considering your feelings of interconnectedness with others [68, 83]. To be ethical, one should think about the situation that each of these others and you are in. Using your experience, you should act in a nurturing and responsible way. This is a key guiding factor to have in the application of ethical principles, as it enhances the importance of considering others outside of yourself. This provides good support for having the goal of fairness, however in itself is not a principle in that it denotes a certain action, which is why it has not been included in the taxonomy.

3.3.4 Other Cultures. Lastly, there is a wide variety of principles proposed in cultures outside of the history of Western ethics. Moral frameworks have been established in societies across the world, including Confucian, Shinto, and Hindu thought as well as religious frameworks like Judaism, Christianity, and Islam [45]. There is a multitude of moral frameworks across cultures with significant variation within these frameworks. Arguably, ethics and culture are inseparable and to understand one you must look at the other. Therefore, ethics must be considered within its cultural context. The reason these principles were not included in the taxonomy was not because they are unimportant, but because they would require a whole taxonomy of their own. An important direction for future work would be to apply the methodology used in this project specifically to non-Western ethical principles, with the goal of forming a taxonomy of such principles. This is crucial to help developers to build cross-cultural ethical technology.

4 PREVIOUS OPERATIONALISATION OF ETHICAL PRINCIPLES

We iterated over the papers identified in our review to conduct analysis of previous operationalisation of ethical principles for Q_o (Operationalisation). We find a variety of techniques used for technical implementation of ethical principles, summarised in Table 5, Table 6 and Table 7. We found that previous literature integrates principles into reasoning capacities in a top-down, bottom-up, or hybrid architecture, summarised in Table 8. We found that practitioners should be specific about which principle(s) they are operationalising, and previous literature suggests that Pluralism may help with this decision. We also found that, abstractly, operationalisation falls into the categories of applying rules for Deontological principles, developing virtues for Virtue Ethics, or evaluating consequences for Consequentialist principles.

4.1 Choosing Technical Implementation

We found that in previous literature, a variety of different technical implementations have been used to encode ethical principles. Expanding upon the categorisation explained by Tolmeijer et al. [96], approaches to encode principles into a format that computers can understand include logical reasoning, probabilistic reasoning, learning, optimisation, and case-based reasoning [85]. This is summarised in Table 5, Table 6 and Table 7.

Table 5. Overview of technical implementation for encoding principles, adapted from [96]

Implementation Type		Description	Examples
Logical Reasoning	Deductive Logic	Knowledge is represented as propositions and rules, from which new propositions can be deduced	Kantian Ethics, Virtue Ethics, Utilitarianism [83]
	Non-Monotonic Logic	Allows for the revision of conclusions when a conflict arises (e.g. from new information)	Kantian Ethics, Maximin, Act Utilitarianism, Rule Utilitarianism, Doctrine of Double Effect [10] Kantian Ethics, Utilitarianism [62]
	Abductive Logic	Drawing the most likely propositions given the premises	Doctrine of Double Effect [71]
	Deontic Logic	For expressing normative propositions related to obligations, permissions, prohibitions, and optionality	Doctrine of Double Effect [41] Virtue Ethics [42] Deontology, Utilitarianism, Doctrine of Double Effect, Do No (Instrumental) Harm [64]
	Rule-Based Systems	System must adhere to a set of rules (many of the above mentioned types of logic are often implemented as rule-based systems)	Maximin [2] Non-Maleficence, Autonomy, Utilitarianism [9] Deontology, Virtue Ethics, Consequentialism [20] Deontology, Utilitarianism [25] Do No Harm [27] Libertarianism [35] Kantian Ethics, Virtue Ethics, Utilitarianism [83]

Implementation Type		Description	Examples
	Event Calculus	Different events can trigger different types of behaviours	Kantian Ethics, Act Utilitarianism, Rule Utilitarianism, Maximin, Doctrine of Double Effect [10] Doctrine of Double Effect [41] Virtue Ethics [42] Kantian Ethics, Utilitarianism [62]
	Knowledge Representation and Ontologies	Focus on how the system can utilise knowledge by improving the quality of data (as opposed to the algorithm alone)	Deontology, Virtue Ethics, Consequentialism [20] Deontology, Utilitarianism [25] Kantian Ethics, Virtue Ethics, Utilitarianism [83]
	Inductive Logic	Premises are induced or learned from examples (rather than being pre-defined)	Deontology [6]
Probabilistic Reasoning	Bayesian Approaches	Using Bayes' rule for computing the likelihood of an event by using prior knowledge	Utilitarianism [8]
	Markov Models	Assumption that future events depend only on the current (and not previous) events	Doctrine of Double Effect [41] Deontology, Kantian, Virtue Ethics, Consequentialism Ethics [84] Kantian Ethics, Utilitarianism [95]
	Statistical Inference	Predicting the chances of future events happening from probability distribution in data	Equality of Opportunity, Proportionalism [33]
Learning	Decision Tree	Supervised learning method to solve classification problems by exploring the decision space as a search tree and computing the expected utility	Non-Maleficence, Autonomy, Utilitarianism [9]
	Reinforcement Learning	Rewards or punishments for actions teach the system what to learn	Maximin [2] Deontology, Kantian Ethics, Virtue Ethics, Consequentialism [84]
	Inverse Reinforcement Learning	System learns reward functions by observing behaviour	Deontology [77]
	Neural Networks	After being trained on cases, can classify new cases based on relevant features	Deontology, Virtue Ethics, Hedonic Act Utilitarianism [46] Virtue Ethics [47]
	Evolutionary Computing	Models evolve in an iterative way; used when there are different competing models of an ethical machine	Virtue Ethics [47]

Implementation Type	Description	Examples
Optimisation	Different actions are assigned different values based on a predetermined formula, and the best value is chosen (e.g. the highest value)	Non-Maleficence, Virtue Ethics, Utilitarianism, (Hedonic) Act Utilitarianism [7] Utilitarianism [8] Non-Maleficence, Autonomy, Utilitarianism [9] Maximin [28] Equality of Opportunity, Proportionalism [33] Egalitarianism, Proportionalism, Utilitarianism, Maximin [59] Maximin [78] Egalitarianism [90] Envy-Freeness [94]
Case-Based Reasoning	Assessing a new situation based on a collection of prior cases	Deontology, Utilitarianism [25] Deontology [69]

4.2 Clarifying the Architecture

In order to engineer morally sensitive systems, practitioners must decide the architecture for integrating ethical principles [98]. These fall within three broad approaches: the top-down imposition of ethical theories; the bottom-up building of systems with goals that may or may not be explicitly specified; a hybrid approach which combines top-down and bottom-up features. Our findings of how ethical principles have been impelemented according to the different architectures is summarised in Table 8.

4.2.1 Bottom-Up Approaches. Bottom-up approaches are understood as machines learning to make ethical decisions by observing human behaviour in actual situations, without being taught any formal rules or moral philosophy [36]. Bottom-up techniques suggested by Tolmeijer et al. [96] include using artificial neural networks, reinforcement learning, and evolutionary computing. An example of this is Noothigattu et al. [77], who use inverse reinforcement learning to align agents with human values by learning policies from observed behaviour. In future work, inverse reinforcement learning could be used to align policies with ethical principles, in a similar way to how Noothigattu et al. [77] align policies with human values. This may improve explainability by assimilating policies with principles which, by their nature, imply logical propositions which can be reasoned about [54]. A challenge of bottom-up approaches, however, lies in the risk that machines learn the wrong rules, or cannot reliably extrapolate to cases not reflected in the training data.

4.2.2 Top-Down Approaches. Top-down approaches install ethics directly into the machine [54], instead of asking the machine to learn from experience (as in bottom-up approaches). Top-down approaches are rule-based: ethics is understood as the investigation of right actions through identifying rules that should be followed in order to perform the morally correct (or at least permissible) action [63]. We find many works use top-down approaches to integrate ethical principles into the reasoning capacities of machines. Dehghani et al. [25] implement Deontological and Utilitarian principles through a combination of qualitative modelling, first-principles logical reasoning, and analogical reasoning. Diana et al. [28] operationalise the principle of minimax (minimise the maximum loss, adapted from Maximin - maximize the minimum) using oracle-efficient learning

Table 6. Technical Implementation of Principles

Implementation Type		Ethical Principles				
		Deontology	Egalitarianism	Proportionalism	Kantian	Virtue
Logical Reasoning	Deductive Logic	–	–	–	[83]	[83]
	Non-Monotonic Logic	–	–	–	[10, 62]	–
	Abductive Logic	–	–	–	–	–
	Deontic Logic	[64]	–	–	–	[42]
	Rule-Based Systems	[20, 25]	[9]	[35]	[83]	[20, 83]
	Event Calculus	–	–	–	[10, 62]	[42]
	Knowledge Representation and Ontologies	[20, 25]	–	–	[83]	[20, 83]
	Inductive Logic	[6]	–	–	–	–
Probabilistic Reasoning	Bayesian Approaches	–	–	–	–	–
	Markov Models	[84]	–	–	[84, 95]	[84]
	Statistical Inference	–	[33]	[33]	–	–
Learning	Decision Tree	–	[9]	–	–	–
	Reinforcement Learning	[84]	–	–	[84]	[84]
	Inverse Reinforcement Learning	[77]	–	–	–	–
	Neural Networks	[46]	–	–	–	[46, 47]
	Evolutionary Computing	–	–	–	–	[47]
Optimisation		–	[7, 9, 33, 59, 90]	[33, 59]	–	[7]
Case-Based Reasoning		[25, 69]	–	–	–	–

Table 7. Technical Implementation of Principles

Implementation Type		Ethical Principles						
		Consequentialism	Utilitarianism	Maximin	Envy-Freeness	Doctrine of Double Effect	Doctrine of Disparate Impact	Do No Harm
Logical Reasoning	Deductive Logic	–	[83]	–	–	–	–	
	Non-Monotonic Logic	–	[10, 62]	[10]	–	[10]	–	–
	Abductive Logic	–	–	–	–	[71]	–	–
	Deontic Logic	–	[64]	–	–	[41, 64]	–	[64]
	Rule-Based Systems	[20]	[9, 25, 83]	[2]	–	–	–	[27]
	Event Calculus	–	[10, 62]	[10]	–	[10, 42]	–	–
	Knowledge Representation and Ontologies	[20]	[25, 83]	–	–	–	–	–
	Inductive Logic	–	–	–	–	–	–	–
Probabilistic Reasoning	Bayesian Approaches	–	[8]	–	–	–	–	–
	Markov Models	[84]	[95]	–	–	[41]	–	–
	Statistical Inference	–	–	–	–	–	–	–
Learning	Decision Tree	–	[9]	–	–	–	–	–
	Reinforcement Learning	[84]	–	[2]	–	–	–	–
	Inverse Reinforcement Learning	–	–	–	–	–	–	–
	Neural Networks	–	[46]	–	–	–	–	–
	Evolutionary Computing	–	–	–	–	–	–	–
Optimisation		–	[7–9, 59]	[28, 59, 78]	[94]	–	[11, 78]	–
Case-Based Reasoning		–	[25]	–	–	–	–	–

algorithms. They apply minimax to analyse fairness considerations in differences between group outcomes. Also considering fairness, Sun et al. [94] formalise Envy-Freeness as rules to examine the trade-off between different fairness allocations. Tolmeijer et al. [96] found that principles can be implemented as rules through logical or case-based reasoning, using domain knowledge to reason about the situation given as input. However, as human knowledge does not tend to be very structured, it needs to be interpreted before it can be used. A difficulty of top-down approaches is thus that human understandings of philosophical rules need to be encoded in a way that machines can understand, which may mean that information is lost or misrepresented.

4.2.3 Hybrid Approaches. Hybrid approaches embody aspects of both top-down and bottom-up approaches. As top-down and bottom-up approaches each embody different aspects of moral sensibility, combining the two in hybrid approaches may result in better implementation of ethical principles [4]. Hybrid examples include Berreby et al. [10], who supplement top-down imposition of rules with bottom-up observation of contextual information, allowing agents to represent and reason about a variety of Deontological and Consequentialist theories. They propose a modular logic-based framework based on a modified version of the Event Calculus, and implemented in Answer Set Programming. Limarga et al. [62] implement principles using non-monotonic reasoning in an event set calculus, which allows for the revision of rules when a conflict arises. Rodriguez-Soto et al. [84] suggest a method that first characterises ethical behaviour as ethical rewards, and then embeds such rewards into the learning environment of the agent using multi-objective reinforcement learning. Their algorithm builds an environment in which it is in the best interest of the agent to act ethically while still pursuing its individual objective. To consider several objectives, they model the environment as multi-objective Markov decision process, which allows the agent to consider both individual and ethical objectives. Following a top-down approach, ethical principles are formalised along normative (whether the action is good or bad) and evaluative dimensions (how good it is). In a bottom-up manner, the principles are then used as reward functions. A benefit of hybrid approaches is that they incorporate both ethical reasoning and empirical observation, which allows context to be taken into account.

Table 8. Architecture for Implementing Principles

Ethical Principles	Bottom-Up	Top-Down	Hybrid
Deontology	Inverse Reinforcement Learning [77] Inductive Logic [6]	Rule Based Systems, Knowledge Representation and Ontologies, Case-Based Reasoning [25] Deontic Logic [64] Case Based Reasoning [69]	Neural Networks [46] Rule-Base Systems, Knowledge Representation and Ontologies [20] Markov Models, Reinforcement Learning [84]
Egalitarianism	–	Statistical Inference, Optimisation [33] Optimisation [7, 59, 90]	Rule-Based Systems, Decision Tree, Optimisation [9]
Proportionalism	–	Statistical Inference, Optimisation [33] Rule-Based Systems [35] Optimisation [59]	–

Ethical Principles	Bottom-Up	Top-Down	Hybrid
Kantian	–	Deductive Logic, Rule-Based Systems, Knowledge Representation and Ontologies [83] Markov Models [95]	Non-Monotonic Reasoning and Event Calculus [10, 62] Markov Models, Reinforcement Learning [84]
Virtue	Evolutionary Computing [47]	Deductive Logic, Rule-Based Systems, Knowledge Representation and Ontologies [83]	Neural Networks [46] Deontic Logic, Event Calculus [42] Rule-Base Systems, Knowledge Representation and Ontologies [20] Markov Models, Reinforcement Learning [84]
Consequentialism	–	–	Rule-Base Systems, Knowledge Representation and Ontologies [20] Markov Models, Reinforcement Learning [84]
Utilitarianism	Rule Based Systems, Knowledge Representation and Ontologies [25]	Deductive Logic, Rule-Based Systems, Knowledge Representation and Ontologies [83] Deontic Logic [64] Optimisation [7, 59]	Non-Monotonic Reasoning and Event Calculus [10, 62] Neural Networks [46] Rule-Based Systems, Decision Tree, Optimisation [9] Bayesian Approaches, Optimisation [8]
Maximin	–	Optimisation [28, 59, 78] Rule-Based Systems, Reinforcement Learning [2]	Non-Monotonic Reasoning and Event Calculus [10]
Envy-Freeness	–	Optimisation [94]	
Doctrine of Double Effect	–	Abductive Logic [71] Deontic Logic [64] Deontic Logic, Event Calculus, Markov Models [41]	Non-Monotonic Reasoning and Event Calculus [10]
Doctrine of Disparate Impact	–	Optimisation [11, 78]	–
Do No Harm	–	Deontic Logic [64] Rule-Based Systems [27]	–

4.3 Specifying the Ethical Principle

Practitioners should specify which ethical principle(s) will be operationalised. This could be aided by the taxonomy we have suggested, which contains a broad array of ethical principles found in AI and computer science literature, with 25 nodes (Figure 2). Being clear about which principle is being used will help designers to further specify what inputs are necessary for their application, which in turn will improve the ethical reasoning capabilities and explainability of how decisions have been made [59].

In specifying the ethical principle, it may be useful to apply the theory of Pluralism. Pluralism states that there is no one approach that is best [83], as human morality is complex and cannot be captured by one single classical ethical theory. Context and various reasoning techniques could be used to choose between appropriate principles. Tolmeijer et al. [96] advocate for further research according to this approach, suggesting the development of multi-theory models where machines can interchangeably apply different theories depending on the type of situation. An example of pluralism being operationalised can be found in Svegliato et al. [95], who propose a framework in which ethical compliance is decoupled from task completion to avoid unanticipated scenarios which do not reflect the values of stakeholders. They suggest that this can be done by implementing a pluralist approach in the form of having an extra moral constraint which represents a moral principle. This allows for the morality of a policy of the decision making module to be evaluated considering its ethical context, leaving room for different ethical principles to be implemented as the ethical rule. Pluralism is a useful approach to have for ethics, and perhaps could be relevant to help developers decide which ethical principle(s) are appropriate.

4.4 Using Rules, Consequences, or Virtues

We find that previous works have operationalised principles in three main ways, depending on the type of principle being used. Deonotological principles have been operationalised, through the application of rules, and then choosing an action based on how it accords to certain rules. Virtue Ethics has been operationalised through the development of virtuous characteristics. Consequentialist principles have been operationalised by evaluating consequences and then choosing an action based on the consequences it produces.

4.4.1 Applying Rules. For Deontological principles, some approaches suggest operationalising principles by applying a set of rules to possible actions to determine which ones would be satisfactory, such as Abney [1], Greene et al. [43], and Berreby et al. [10]. Examples of this would be applying the rule that the disparity of preference satisfaction for stakeholders should be minimised, extracted from the principle of Egalitarianism [75]. Another example is applying the rule that stakeholders should be treated proportionally based on their contributions to production [59]. However, due to the abstract nature of ethics, there are difficulties that arise in finding appropriate ways to encode ethical principles in concrete rules [96]. One aspect of these difficulties may lie in deciding if rules should be interpreted as strict or defeasible. For example, an essential part of Kantianism [51] is that the reasons for actions must be universalizable to all agents and therefore perhaps this rule should be strict. However, arguably this could permit actions that are bad according to other principles [1], and this suggests that it should be defeasible. Creating systematic ways of encoding ethical principles into rules, including understanding whether rules should be strict or defeasible, to use in the context of STS could thus be a direction for future research.

4.4.2 Developing Virtues. For Virtue Ethics, ethicality stems from the inherent character of an individual [1, 13, 52, 76, 98, 101]. To solve a problem according to this theory, virtuous characteristics should be applied [83]. Thus, the theory can be operationalised through the instantiation of virtues

[96]. This is exemplified in Govindarajulu et al. [41], who understand virtues as being learnt by experiencing the emotion of admiration when observing virtuous people, and then copying the traits of those people. This is instantiated by using computational formal logic to formalise emotions (in particular the emotion of admiration), represent traits (which in this example will be virtuous), and establish a process of learning traits. To formalize virtues, the authors use the deontic cognitive event calculus, which is a computational formal logic. More specifically, it is a quantified multi-operator modal logic (which can take sentences as arguments and allows for possible states [85]) that includes the event calculus (different events trigger different types of behaviours), which is a first-order calculus used for reasoning over time and change. By formalising emotions (admiration) in this way, agents associate admiration with the actions of others. Traits are formalized as a series of instantiations of a type of behaviour. If enough admiration is felt for these traits, the agents learn the traits, thus instantiating virtues. Therefore, the development of virtuous characteristics or traits is needed in order to implement Virtue Ethics into machines. However, there Virtue Ethics can be difficult to apply to individual situations [86], and there are thus challenges that arise with the application of Virtues across time and culture [96]. Future research could therefore incorporate the applicability of Virtue Ethics across different contexts in STS.

4.4.3 Evaluating Consequences. Consequentialist principles may be operationalised by evaluating the consequences of different actions [62]. This could be done by ranking agents' options in terms of how much aggregate welfare their consequences have [93]. Dehghani et al. [25] specify this with the principle of Utilitarianism by selecting the choice with the highest utility. Instead of choosing the consequence with the most welfare, Ajmeri et al. [2] choose to operationalise the principle of Prioritarianism by improving the minimum experience in the consequences of an action. Another way consequences are used is in operationalising the principle of Envy-Freeness, in which Sun et al. [94] promote the outcome with the lowest levels of envy between groups or individuals. Other principles, such as the Disparate Impact Doctrine look at the representation of groups in consequences and posit that a satisfactory outcome would have equal or proportional treatment [78]. However, there are issues that arise in predicting all of the possibilities that an action could produce, as this could be computationally challenging, requiring complex calculations that may be faulty [43]. The simulation of consequences in the context of reasoning capacities used to govern STS could therefore be a direction for future research. There are limitations of not being able to simulate all possible consequences of an action in environments that are non-deterministic (actions do not have a certain effect) and probabilistic (using probabilities to represent uncertainty). Therefore, simulating consequences in STS could begin with studying deterministic environments, in which the next state of each action is known, and consequences are accessible. Findings from this could then be expanded to a broader scope of environment type.

5 OPERATIONALISING ETHICAL PRINCIPLES IN SOCIOTECHNICAL SYSTEMS

Based upon the findings of the survey, we suggest ways in which ethical principles could be operationalised in a sociotechnical system. Stakeholders govern sociotechnical systems by promoting norms that align with their values [18]. However, dilemmas may arise in which values and norms conflict. Incorporating normative ethical principles in reasoning about values and norms may help develop equitable governance of sociotechnical systems [99]. In Table 9 and Table 10, for each principle in our taxonomy (Figure 2) we suggest potential inputs, a rule that could be applied to these inputs to operationalise the principle, and potential outputs from applying the rule to the inputs.

Table 9. Operationalising Deontological Principles in STS.

Principle	Inputs	Rule	Outputs
	Stakeholder values and norms		
Egalitarianism	+ Stakeholder rights	Give stakeholders equal weightings	Decision about values and norms that promotes equal rights of stakeholders
Non-Maleficence Egalitarianism	+ Definition and quantification of harm	Equally distribute harms amongst stakeholders	Decision about values and norms where harm is equally distributed
Equality of Opportunity	+ Relevant opportunities	Ensure opportunities are equally available to all stakeholders	Decision about values and norms that promotes equal access to opportunity
Luck Egalitarianism	+ Definition and quantification of luck	Mitigate for the effects of luck (e.g. by giving stakeholders a weighting based on how much luck they have) and ensure that benefits are distributed as a result of stakeholders own choices	Decision about values and norms that mitigates for the effects of luck
Autonomy Egalitarianism	+ Definition and quantification of autonomy	Ensure that minimum levels of autonomy are reached	Decision about values and norms that promotes autonomy
Proportionalism	+ Stakeholder rights + Stakeholder contributions to production	Adjust stakeholder weightings according to contribution to production	Decision about values and norms that reflects the rights of stakeholders according to their contribution
Libertarian Proportionalism	+ Stakeholder rights + Stakeholder total contribution at the time of consent	Adjust stakeholder weightings according to total contribution at the time of consent	Decision about values and norms reflecting the rights of stakeholders, which represent their contribution at the time of consent
Desert-Based Proportionalism	+ Stakeholder rights + Definition and quantification of luck	Adjust stakeholder weightings according to their contribution, discounting for the effects of luck (i.e. weight = contribution - luck)	Decision about values and norms reflecting the rights of stakeholders, which represent their contribution minus the effects of luck
Kantianism	+ Reasons for acting	Ensure that no person is treated as a means to an end	Decision about values and norms which considers reasons for acting to ensure that no person is being treated as a means to an end

Table 10. Operationalising Teleological Principles in STS.

Principle	Inputs	Rule	Outputs
	Stakeholder values and norms		
Virtue	+ Traits of stakeholders	Prioritise the preferences of stakeholders with virtuous traits	Virtuous stakeholders decide about values and norms, as problems are solved through the application of virtuous characteristics
Utilitarianism	+ Utility of consequences	Maximise the sum of utility	Decision about values and norms which results in the consequence with the highest utility
Hedonic Act Utilitarianism	+ Net pleasure of the consequences of each action	Action that maximises net pleasure	Decision regarding values and norms which leads to the consequence with maximum pleasure
Rule Utilitarianism	+ Consequences of moral rules	Choose the rule that leads to the best overall consequences	Values and norms are prioritised according to the rule with the best consequences
Maximin	+ Utility of consequences	Maximise the minimum utility	Decision about values and norms with the consequence that improves the worst-case experience
Envy-Freeness	+ Quantification of envy of stakeholders in consequences	Minimise levels of envy	Decision about values and norms that leads to the consequence with the lowest levels of envy
Doctrine of Double Effect	+ Consequences of actions	Only choose actions with positive consequences	Decision about values and norms which leads to positive consequences; negative consequences may be permissible if they are unforeseen
Disparate Impact Doctrine	+ Impact on stakeholders in consequences	Ensure impact is equally or proportionally distributed	Decision about values and norms where impact is equally or proportionally distributed amongst stakeholders in the consequences
Do No (Instrumental) Harm	+ Definition and quantification of harm in consequences	Inflict no harm (Do No Instrumental Harm allows for harm as an unintended side effect)	Decision about values and norms whose consequences do not cause harm

6 GAPS IN OPERATIONALISING ETHICAL PRINCIPLES IN COMPUTER SCIENCE AND ARTIFICIAL INTELLIGENCE

We now examine existing gaps in ethics and fairness research in computer science and artificial intelligence literature, specifically in relation to implementing these principles in multiagent systems.

6.1 Expanding the Taxonomy

Key gaps include a lack of research on lesser-utilised principles. We suggest that future research could include these less commonly seen principles, or incorporate a wider array of principles. This includes researching principles from other cultures outside of the Western doctrine. Not only would this allow for agents that have better ethical reasoning capacities, but it would also aid the explainability of AI agents. When looking at why an agent made a particular decision, one could refer to the exact principle they used in their explanation. This will aid the accessibility and fairness of technology, as it can better apply to groups of stakeholders from different backgrounds.

6.2 Implementing Ethical Principles in STS

The majority of research identified did not explicitly tie in to STS. Tolmeijer et al. [96] study how ethical principles relate to machine ethics, but do not consider the relation of ethical principles to values and norms within the context of STS. Ajmeri et al. [2] broadly reference the principles of Egalitarianism and Utilitarianism within the context of utilising values and norms for ethical reasoning, however this research may benefit from the consideration of other ethical principles to enable broader applicability. Future work could thus adapt methodologies suggested by these authors to the context of STS.

6.3 Resolving Ethical Dilemmas

Lastly, the findings show that there are difficulties associated with every ethical principle identified. This implies that for each principle, there will be some situations in which it leads to an unfair outcome. Ethical dilemmas are thus scenarios in which the application of an ethical principle leads to an unfair outcome, cannot support one action over another, or conflicts with another ethical principle. When a principle cannot support one action over another, Azad-Manjiri [9] resolves the dilemma by examining how similar decisions have been made previously. If no similar decisions have been made previously, an action is selected at random. However, relying on random choice may not result in the most ethically appropriate action. Alternatively, ethical dilemmas may be mitigated through the use of Pluralist approaches, in which a variety of principles can be weighed against one another in order to find the fairest answer. To aid this, the use of Particularism (the incorporation of relevant contextual factors in ethical reasoning to identify if a certain feature is morally relevant or not, [96]), could help to identify which principle is the most appropriate in that setting. There is thus a gap in how to address the difficulties that may arise with the implementation of a particular ethical principle, and this may be addressed in future work through the use of Pluralist and Particularist approaches.

7 CONCLUSION

In order to better address the pursuit of ethical AI, research must be human-centred [31]. Shifting the perspective to macro ethics of STS in which the governance of systems is examined is crucial to better achieve this [18]. In the governance of STS, stakeholders attempt to align norms with their values. However, dilemmas in decision making can arise when stakeholders have different preferences [75]. To resolve these dilemmas in satisfactory ways which promote a higher goal of fairness, ethical principles can help to determine the moral permissibility of actions [64, 69]. In this survey, we have identified a broad variety of ethical principles which have been previously operationalised in computer science (Section 3). We have also identified key aspects of operationalising ethical principles in AI, including choosing technical implementation, clarifying the architecture, specifying the ethical principle, and using rules, consequences or virtues (Section 4). We found that previous literature did not operationalise ethical principles in STS, and suggested how this could be done on an abstract level (Section 5). Key gaps that highlight future research directions include expanding the taxonomy, implementing principles in STS, and resolving ethical dilemmas where principles conflict or lead to unfair outcomes (Section 6). We envision that the findings of this survey will aid the development of more ethical STS through incorporating ethical principles in reasoning capacities used in governance.

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A OVERVIEW OF METHOD

Figure 3 visualises the method used in order to answer the research questions. This was in a concurrent two-part process of analysing principle identification (Q_P) and principle implementation (Q_O) in literature. Qualitative analysis of works was conducted by reading through and summarising key points, which were then put into relevant classifications of which principles they related to, and the types of research that they were (seen in Table 1). These individual analyses were then aggregated to examine the findings as a whole. Some works were more theoretical, exploring the existence of principles and how they might relate to computer science (e.g., [59]). These works were useful for the identification of principles (Q_P). Other research took established principles and implemented them, which helped to answer Q_O (e.g., [94]). Some works had a mixture of both identification and implementation (e.g., [54]). This analysis was performed in consultation with a second author who critically examined the works being reviewed and the findings extracted by the first author.

B THREATS TO VALIDITY AND MITIGATION

Five threats to validity arise, which are summarised here, alongside attempted mitigations. The first threat identified is that only papers that are written or translated to English are included in our review for developing a taxonomy. This means that relevant research in other languages

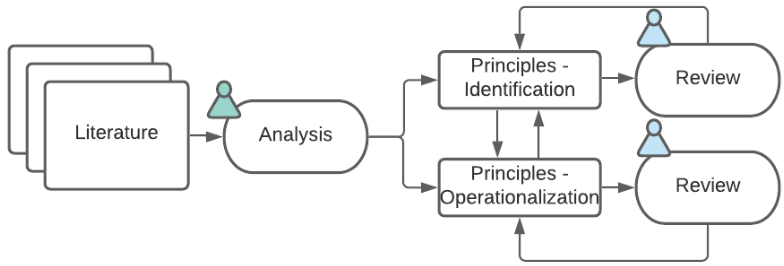

Fig. 3. Methodology to Extract Principle Identification and Operationalisation from Literature

may be missed, which could contribute to cultural bias and thus threaten both the external and internal validity of the study. The internal validity is threatened by missing ethical principles that are referenced in other languages, and the external validity is threatened by diminishing the cross-cultural application of the findings. This is mitigated by seeking papers with international authorship, but it is recognized as an outstanding issue that could be resolved through future research in applying the methodology to other languages.

A second threat to internal validity is the potentiality of missed keywords, which may again lead to relevant research being excluded. The initial search string is based off of preliminary research, and as the review continues more key terms are identified. To address this concern, it is ensured that the aims of the review are carefully scoped which allows for the identification of a good array of initial relevant terms. As more terms are identified, it is ensured that relevant citations are followed and those terms are included.

There is a related third threat of missing resources which has similar implications to the internal validity of the study. The topic studied here relates to a broad area of research, and areas such as Human-Computer Interaction and Software Engineering are not explicitly included in searches but may contain relevant research. This threat is addressed by using two large online libraries as the initial resources, which link to a variety of other resources. Citations from selected studies are also followed, broadening the scope of publications. However, future research could also include reproducing the methodology in these other areas.

Fourth, time limitations threaten the internal validity as there is only time to search the first five pages of results (plus citations). This may mean that there is relevant work beyond these pages that there is not enough time to pursue. To do the best research possible within this time limit, citations are pursued, and Kitchenhams's [55] guidelines for a systematic literature review are broadly followed. This helps to effectively identify relevant research. On the other hand, this limitation could lead to further research in this area by applying our methodology to the analysis of more studies than those identified here.

The fifth issue of researcher bias also threatens the internal validity as it can sway the results in a particular direction rather than being objective. This is mitigated by having a secondary reviewer who critically analyses results and makes suggestions to help the primary reviewer improve the study. This is also tackled by basing the study selection criteria on the research question and defining it before the review is begun.

Table 11. Inclusion and Exclusion Criteria

Inclusion
Published works found in: AIES, FAccT, AAAI, IJCAI, (J)AAMAS, TAAS, TIST, JAIR, AIJ, Nature, Science
Individual and/or group fairness
Multiple-user social dilemmas
Normative ethics and multiple-user AI and/or MAS
Normative ethics and STS
Normative ethical principles and AI
Bias when related to ethical principles

Exclusion
Works about meta-ethics or applied ethics outside of computer science
Studies about specific ML methodology
Non-social dilemmas
Non-ethical studies of multiple-user AI and/or MAS
Non-ethical studies of STS
AI keystones
Studies about bias without reference to ethical principles