Re(l)ality:

The View From Nowhere vs. The View From Everywhere

Nicola Bamonti[1,2]

[1]Department of Philosophy, Scuola Normale Superiore, Piazza dei Cavalieri, 7, Pisa, 56126, Italy

[2]Department of Philosophy, University of Geneva, 5 rue de Candolle, 1211 Geneva 4, Switzerland

Abstract

Using the fiber bundle framework, this work investigates the conceptual and mathematical foundations of reference frames in General Relativity by contrasting two paradigms. The *View from Nowhere* interprets frame representations as *perspectives* on an invariant equivalence class, while the *View from Everywhere* posits each frame representation as constituting a fully-fledged reality itself. What emerges is a conception of reality that I term "*Relality*." The paper critically examines the philosophical and practical implications of these views, with a focus on reconciling theory with experimental practice. Central to the discussion is the challenge of providing a *perspicuous* characterisation of ontology. The *View from Nowhere* aligns with the so-called ' sophisticated approach to symmetries' and complicates the empirical grounding of theoretical constructs. In contrast, the *View from Everywhere* offers a relational ontology that avoids the abstraction of equivalence classes.

Contents

1 Introduction

In theoretical frameworks known as *gauge theories*, such as General Relativity (GR), the concept of *observables* refers to quantities that remain unchanged under specific transformations called *gauge transformations* (Dirac, 1964). These are transformations that do not alter the physical content of the theory, also referred to as the 'observable content'. Consequently, gauge transformations are often understood as mere mathematical re-expressions of the theory's formalism and are seen as indicators of a *representational redundancy* in the theory, where multiple mathematical descriptions correspond to the same physical reality.[1]

The standard assumption in physics is that a procedure of 'gauge-fixing' is necessary to remove the descriptive redundancy, ensuring a *unique* description of physical configurations through the definition of observable quantities.[2] Along these lines, this paper explores how observables are constructed and interpreted in GR.

For a theory to achieve empirical validity, its gauge-invariant observables must correspond to measurable quantities, facilitating comparisons between theoretical predictions and experimental observations. This correspondence is a critical criterion for the acceptance of any scientific theory.[3]

All measurements are inherently local, as they rely on observations within specific regions of spacetime. Much of our experience involves measuring locally defined variables at particular spacetime points or within localized regions. As Gary and Giddings (2007) emphasise, *"all we can truly observe is localised — we have no access to infinity."* In GR, gauge symmetries are expressed as diffeomorphisms. As a result, any quantity defined locally in spacetime does not remain invariant under these transformations, raising challenges for constructing local, gauge-invariant observables.

In a diffeomorphism-invariant theory, variables can be broadly categorized into two types: (1) highly non-local quantities, which are defined across the entire spacetime, such as integrals over

[1] 'The 'gauge argument' is well known in both physical and philosophical literature (see Berghofer et al. (2023) for a recent overview). I will therefore say no more on the subject, assuming the reader is familiar with the main concepts summarised above. As a final point, it should be pointed out that the presence of gauge symmetries is closely related to the threat of indeterminism. It is precisely to save the theory from this threat that the concept of gauge was introduced in Dirac (1964).

[2] It is interesting that the verb 'fix' in English can mean two things, both of which are correct in this context: (i) *adjusting* the formalism to eliminate redundant degrees of freedom; (ii) *setting* a specific condition (called the gauge condition) from a shortlist of possible conditions, in order to construct a single observable quantity from redundant degrees of freedom.

[3] Although a theory cannot be entirely confirmed or falsified by experimental evidence, its ability to allow meaningful comparisons with reality is essential to avoid being labeled as ad hoc (Leplin, 1975).

global regions, and (2) relational quantities, which are constructed by correlating field values. This work focusses primarily on the second category, commonly referred to as *relational observables*.

A recent approach to constructing local observables in GR was introduced by Rovelli (2002b) and formalised by Dittrich (2006, 2007). This approach involves correlating two partial observables—quantities that are individually gauge-variant—to form a gauge-invariant complete observable. These complete observables embody a relational notion of locality: instead of being situated within a fixed spacetime background, physical states are defined in relation to other fields. In simpler terms, a complete observable represents the value of one partial observable when the value of another is specified.

This relational framework is closely connected to the role of reference frames in GR, as discussed by Bamonti (2023). Reference frames offer a structured way to define gauge-invariant quantities relationally. In practice, constructing relational observables often involves treating one partial observable as a spatiotemporal reference frame for another, thereby highlighting the inherently relational nature of locality in this framework.

As Bamonti (2023); Bamonti and Gomes (2024b) argue, one way to construct local, complete observables in GR is through *dynamically coupled reference frames*. Specifically, when a pair of partial observables forms a valid solution to the dynamics of the theory, only the *diagonal* action of a dynamical symmetry (such as a diffeomorphism in GR) preserves this solution.

This paper addresses a central question: how should we interpret two local observables expressed in terms of distinct reference frames? Two primary views aim to answer this question.

The first, the, *View from Nowhere* is the dominant perspective in the literature. It asserts that changing a reference frame does not affect the physical content of the description, as a reference frame provides merely a *perspective* on a shared, objective reality. This idea has its roots in Special Relativity, where different inertial reference frames offer distinct perspectives on a Lorentz-invariant physical reality. Prominent examples of this view include the *perspective-neutral framework* introduced by Vanrietvelde et al. (2020) and related work by Giacomini et al. (2019) and Kabel et al. (2024). Importantly, I will use the term 'perspective' in the ordinary deflated sense throughout the paper.[4]

[4]The term 'perspective' is widely used in the philosophy of science. For example, Michela Massimi uses the notion of perspective in terms of a historically and culturally situated epistemic lens within a debate on scientific realism Massimi (2022).

The *View from Everywhere*, proposed in this paper, challenges the assumption of an underlying objective reality. I argue that there is no direct analogy between GR and Special Relativity in this context. While Special Relativity relies on a fixed, Lorentz-invariant framework, GR introduces local gauge-invariant quantities that are not necessarily frame-invariant. Local relational observables, although gauge-invariant, can differ numerically when expressed in different reference frames. Consequently, the View from Everywhere suggests that frame representations are not merely perspectives on an objective reality; they are fundamental realities themselves.

To clarify the terminology used in this work, I distinguish between spatiotemporally explicit and implicit quantities, as well as local and non-local quantities. Additionally, the term ”invariant” requires careful consideration, particularly in distinguishing between independence and freedom.

Table 1 provides an overview of these distinctions, presenting a structured summary of the various types of quantities in GR along with their defining characteristics.[5]

Table 1: Summary of distinctions between different types of quantities that can be defined in GR.

$g_{ab}(p)$	Spatiotemporally explicit and local	Frame free	Gauge-variant
$\int g_{ab}(p)\, dx^a dx^b$	Spatiotemporally explicit and non-local	Frame free	Gauge-invariant
$[g_{ab}]$	Spatiotemporally implicit	Frame free	Gauge-invariant
$g_{IJ}(\phi)$	Frame explicit and local	Frame dependent	Gauge-invariant or not, depending on ϕ
$\int g_{IJ}(\phi)\, d\phi^I d\phi^J$	Frame explicit and non-local	Frame independent	Gauge-invariant
$[g_{IJ}]$	Frame implicit	Frame independent	Gauge-invariant

In the context of non-relational quantities, we can distinguish quantities that are:

[5]Notice that a metric $g_{\mu\nu}(x^\rho)$ written in some coordinate system $\{x^\rho\} \in \mathbb{R}^N$ *is* a frame-free, spatiotemporally explicit, local, and gauge-variant object.

i) **Spatiotemporally explicit:** expressible by a single model as explicit functions of points of $\mathcal{M}$. They can be distinguished into:

i.a) **Spatiotemporally local:** locally expressible by a single model, e.g. the metric tensor on the manifold $g_{ab}(p)$. Such objects are not gauge-invariant

i.b) **Spatiotemporally non-local:** non-locally expressible by a single model, e.g. the total volume integral of a given metric. Such objects are gauge-invariant

ii) **Spatiotemporally implicit:** not expressible by a unique spatiotemporal model, but only as equivalence classes. They are usually denoted using square brackets: for example, $[g_{ab}]$. Such objects are gauge-invariant.

Once reference frames are introduced, it is straightforward to construct relational quantities. Analogously as done above, we can distinguish various possible formulations of relational objects in GR, when written in terms of reference frames. Here, I provisionally denote a reference frame without further specification as a set of 4 scalar quantities $\phi^{(I)} \mid_{I=1,\ldots,4}$ associating a real quadruple with each point P of the manifold. (See the next section for a more detailed discussion). We can distinguish between relational quantities that are:

I) **Frame explicit:** expressible by a single model as explicit functions of a reference frame. They can be distinguished into:

I.A) **Frame local:** locally expressible by a single model $g_{IJ}(\phi)$ (see the next section for the detailed construction and meaning of symbols). Such objects are gauge-invariant. However, using uncoupled reference frames they could also be only relational, but not gauge-invariant (see Bamonti and Gomes (2024b)).

I.B) **Frame non-local:** non-locally expressible by a single model, e.g. the total volume integral of a given gauge-invariant metric g_{IJ}. Such objects are always gauge-invariant, independently if the reference frame is coupled with the metric or not

II) **Frame implicit:** not expressible by a unique spatiotemporal model, but only as equivalence classes. In such a case, the equivalence class is the collection of all spatiotemporally explicit frame-explicit models. They can be denoted using square brackets: for example $[g_{IJ}]$, which constitutes a gauge-invariant object. See section 4 for a discussion on such object.

NB: of course, a frame explicit object will be also spatiotemporally explicit, *in the specific sense enclosed by the relational locality* typical of the use of reference frames. To avoid confusion, I have decided to distinguish between frame-explicit and spatiotemporally explicit objects, preserving the term 'spatiotemporal' to indicate objects written in terms of manifold points (if it helps, the reader may also interpret a spatiotemporally explicit object as 'manifold explicit').[6]

Finally, following and expanding Wallace (2019)'s work, in which he distinguishes between the concepts of (coordinate) *independence* and (coordinate) *freedom*, I distinguish between:

1. **Reference frame-dependence:** a quantity is reference frame-dependent if its definition depend on the reference frame in which is defined

2. **Reference frame-independence:** a quantity is reference frame-independent if its definition does not depend on the reference frame in which it is, however, defined

3. **Reference frame-freedom:** a quantity is reference frame-free if does not need any reference frame to be defined.

The following sections delve deeper into these ideas, exploring the implications of reference frame dependence and offering a comprehensive framework to interpret relational observables in GR. Furthermore, the introduction of the View from Everywhere allows me to provide a *perspicuous* characterisation of relational ontology (section 4), which is not readily provided in the View from Nowhere (section 3).

[6]The concept of spacetime lacks a universally agreed definition, and its interpretation varies across different frameworks. It may be understood as: (i) the manifold $\mathcal{M}$; (ii) the combination $(\mathcal{M}, g_{ab})$, which consists of the manifold equipped with the metric field representing the gravitational field; or (iii) the gravitational field g_{ab} alone. In interpretations (i) and (ii), the distinction lies in whether $\mathcal{M}$ is considered an ontologically independent entity—a stage upon which dynamical variables act—or whether it is inseparable from the fields. Interpretation (iii), however, treats $\mathcal{M}$ as a purely mathematical construct without ontological status (see Rovelli and Gaul (2000); Rovelli (2006); Rovelli and Vidotto (2015); Einstein et al. (2015)). An additional perspective considers spacetime as an *emergent* structure, defined in terms of observables in the Dirac (gauge-invariant) sense. These observables correspond to the *happening* of events, which specify the "when" and "where" of physical phenomena in a relational manner. Accordingly, the 'where and when' are consequential to the happening of an event (which is a gauge-invariant observable). So it is the happening of the event that determines where and when it happens and not the event happening at a where and when. In this paper I choose the more conservative option and identify space-time with option (ii).

2 The Bundle Formalism: A Gauge Perspective on Reference Frames

In this section, I use the fiber-bundle formalism to describe reference frames and relational observables. This approach, widely used in foundational studies of gauge theories (see e.g. Healey (2007); Weatherall (2016)), is primarily attributed to the work of Gomes (see, e.g., Gomes (2023a,b) for a rigorous treatment). Let M represent the space of models m of the theory. The space M can be described as a principal bundle with S as its structure group and $[M] := \{[m] \mid m \in M\}$ as its base space, where $[m]$ identifies the equivalence class of models under the transformations of $\mathcal{S}$. In this formalism, selecting a reference frame involves defining a *unique* section map $\sigma : [m] \to \sigma([m]) \in M$, which smoothly maps equivalence classes of models to individual models in the space . This corresponds to choosing a submanifold in the fiber bundle that intersects each fiber $\mathbb{F}_m := \mathrm{pr}^{-1}([m])$ exactly once, with $\mathrm{pr} : m \to [m]$ being the projection map.

Choosing a reference frame can also be interpreted as selecting a specific gauge. In fact, the choice of a gauge is equivalent to the choice of a reference frame (see Dittrich (2007) for insights on the relationship between gauge-fixed observables and relational observables). In gauge theories with a principal fiber bundle structure, gauge-fixing determines a section through the fiber bundle. Given a symmetry group S, each fiber corresponds to a *gauge orbit* — the set of all configurations of a field that are related by gauge transformations, generated by the constraints of the theory. Specifically, there exists a one-to-one correspondence between each gauge orbit and the equivalence class of models under the symmetry $s \in S$. More concretely, for $m \in M$ and $s \in S$, the orbit O_m is defined as $O_m = \{m_s \mid s \in S\}$, where m_s denotes the model to which the transformation s is applied. Due to the symmetry of the theory, the model space includes significant redundancy. The physical content of the theory is captured by a single representative from each gauge orbit, while other models within the same orbit are redundant, isomorphic copies.[7] This redundancy is typically resolved by fixing a gauge. Similarly, in GR, one fixes a reference frame through a coordinate gauge condition (see Bamonti (2023); Gomes (2024b)).

[7]This does not imply that gauge freedom constitutes mere ”descriptive fluff” (see Earman (2004)). On the contrary, the correspondence between gauge-fixing and reference frame selection highlights the relational nature of physics. The additional degrees of freedom are meaningful as they represent the possible ways a system can form observables relative to another system. Isomorphic models provide ”handles” through which systems can couple; see Rovelli (2014) and Adlam (2024).

In the following, I provide a concrete example to illustrate the reference frame formalism and the gauge-fixing procedure within the bundle framework. This example serves as a foundation for discussing the two distinct perspectives on interpreting local observables in GR.

Let the space of models be $M = \mathrm{Lor}(\mathcal{M})$. This denotes considering tuples $\langle \mathcal{M}, g_{ab} \rangle$ as possible models, focusing on 'vacuum' GR.[8] The set $\mathrm{Lor}(\mathcal{M})$ can be interpreted as a principal bundle with $\mathcal{S} = \mathrm{Diff}(\mathcal{M})$ as its structure group and $[\mathrm{Lor}(\mathcal{M})] := \{[g_{ab}], g_{ab} \in \mathrm{Lor}(\mathcal{M})\}$ as its base space.[9] Each equivalence class $[g_{ab}]$ consists of diff-related metrics:

$$[g_{ab}] := \{g_{ab}, (d^* g)_{ab}, \dots\}.$$

Suppose we construct four scalar quantities, $\mathfrak{R}_g^{(I)}$, $I = 1, \dots, 4$, from the metric g. These are known as *Kretschmann-Komar scalars*, named after Kretschmann (1918) and Komar (1958) (see also Bergmann and Komar (1960, 1962)).[10] The set $\{\mathfrak{R}_g^{(I)}\}$ provides a spatiotemporal reference frame for the metric field itself, aligning with the relational strategy: "Rather than fixing an observable at specific coordinates, its location is defined relative to features of the state" (Harlow and qiang Wu, 2021).

A reference frame can be defined as a physical system yielding a *local* diffeomorphism:

$$\mathfrak{R}_g^{(I)} := (\mathfrak{R}_g^{(1)}, \cdots \mathfrak{R}_g^{(4)}) : U \subseteq \mathcal{M} \to \mathbb{R}^4, \tag{1}$$

which *uniquely* assigns four numbers to each point in U. Using this frame, tensors like the metric g_{ab} can locally be 'coordinatised' by $\{\mathfrak{R}_g^I\}$. Specifically, for all isomorphic models, the gauge-invariant relational observable

$$g_{IJ}(\mathfrak{R}_g) := \left[\mathfrak{R}_g^{-1}\right]^* g_{ab}$$

produces a set of 10 scalar functions indexed by I and J, constructed from the metric tensor and

[8]A typical model $M \ni m = \langle \mathcal{M}, g_{ab}, \phi \rangle$ consists of a manifold $\mathcal{M}$, a (Lorentzian) metric g_{ab}, and some matter field ϕ.

[9]Field theories like GR face challenges in defining a $[\mathrm{Lor}(\mathcal{M})] \times \mathrm{Diff}(\mathcal{M})$ product structure, even locally (this is consistent with the general impossibility of defining a global reference frame). This is viable only for globally hyperbolic spacetimes admitting a CMC foliation. Furthermore, the Gribov obstruction limits the construction to a local product structure (Gribov (1978); Henneaux and Teitelboim (1994).

[10]Komar (1958)) derived these scalars using an eigenvalue problem involving the Riemann tensor R_{abcd} and an anti-symmetric tensor V_{cd}: $R_{abcd} - (g_{ac}g_{bd} + g_{ad}g_{bc})V_{cd} = 0$.

its derivatives.[11] Its gauge-invariance follows from the chain rule for the transformation of $\mathfrak{R}_g$:

$$\forall d \in Diff(\mathcal{M}), \quad [\mathfrak{R}_g^{-1}]^* g_{ab} = [\big(d^*\mathfrak{R}_g\big)^{-1}]^*(d^*g)_{ab}. \tag{2}$$

Thus, using this quadruple, we achieve a unique, gauge-invariant metric representation. Given initial data for g_{ab}, the dynamical evolution of $g_{IJ}(\mathfrak{R}_g)$ is uniquely determined because $\mathfrak{R}_g^{(I)}$ are dynamically coupled to g_{ab} — being functions of the metric itself. Consequently, diffeomorphisms act *diagonally* to preserve solutionhood: if $(g_{ab}, \mathfrak{R}_g^{(I)})$ is a possible solution, then *only* $\big((d^*g)_{ab}, d^*\mathfrak{R}_g^{(I)}\big)$ is a still a possible solution.

This encapsulates the concept of a 'relational, gauge-invariant observable' and a 'reference frame'.[12]

The choice of $\mathfrak{R}_g$ as a reference frame can be formalised through a choice of a gauge. This allows us to fix a reference frame by a condition — *valid for all the isomorphic models* — that the models satisfy. This is most directly accomplished by postulating some constraint $F_{\mathfrak{R}_g} \in C^\infty(\mathcal{M})$, such that:

$$\forall g_{ab} \in Lor, \exists! f_{\mathfrak{R}_g} \in Diff(M) \quad | \quad F_{\mathfrak{R}_g}(g_{ab}) = 0, \tag{3}$$

where $f_{\mathfrak{R}_g}$ acts as the equivalent of a section map within the fiber-bundle framework. Specifically, this diffeomorphism $f_{\mathfrak{R}_g} : g_{ab} \to f^*_{\mathfrak{R}_g} g_{ab}$ serves as a projection operator, uniquely mapping any element of a given fiber to the section's image. It is also called the *projection operator for the section*.[13] More precisely, $f_{\mathfrak{R}_g}$ is the embedding map, *acting within a fibre*, from the fibre bundle manifold of models $Lor(\mathcal{M})$ to the *image* of the section map, and it is characterised by the auxiliary condition $F_{\mathfrak{R}_g}(g_{ab}) = 0$. The constraint $F_{\mathfrak{R}_g}(g_{ab}) = 0$ defines a 'level surface' of the section map

[11] Viable reference frames $\mathfrak{R}_g$ must be locally invertible. In spacetimes with continuous symmetries, such as metrics admitting Killing vectors, this condition may fail, making the scalars *linearly* dependent. Thus, linear independence of $\{\mathfrak{R}_g^{(I)}\}$ is necessary for their viability as a reference frame. We should distinguish linear (in)dependence from functional (in)dependence. For example, one could have zero physical degrees of freedom — that is *functional* dependence — and still have a viable reference frame.

[12] Strictly, a 'relational observable' is not automatically gauge-invariant (Bamonti and Gomes, 2024b).

[13] The projection corresponding to the choice of a reference frame can be written down in terms of coordinate charts. For instance, in GR two common gauge-fixings are the De Donder gauge in the Lagrangian sector which corresponds to the condition $F(g) = \partial_\mu(g^{\mu\nu}\sqrt{g}) = 0$, and the CMC gauge in the Hamiltonian sector: $F(h^{ij}, \pi_{ij}) = h^{ij}\pi_{ij} = const$. The former corresponds to the use of coordinates that satisfy a relativistic wave equation $\Box x^\mu = 0$. The latter, selects global simultaneity *homogeneous* 3-hypersurfaces Σ_τ, parametrised by a universal time τ. Notice that both are *only partial* gauge-fixings.

along the fibers, effectively making the choice of a reference frame (or section) analogous to a gauge-fixing procedure. See Figure 1.[14] [15]

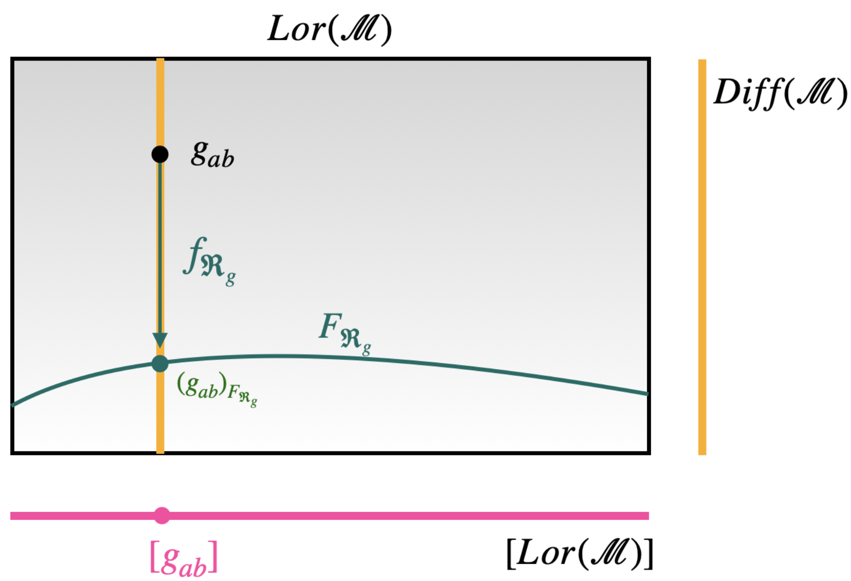

Figure 1: The space of models $Lor(\mathcal{M})$ with its gauge group $Diff(\mathcal{M})$. Each point corresponds to a particular metric g_{ab}. A reference frame $\mathfrak{R}_g$ picks out a *unique* representative $(g_{ab})_{F_{\mathfrak{R}_g}}$ for each fibre $\mathbb{F}_g$. This is achieved via the *projection map* $f_{\mathfrak{R}_g}$ which projects a model within a fibre on the intersection between the fibre and a choice of section, whose 'level surface' is represented by $F_{\mathfrak{R}_g}$. Models belonging to the same fibre are taken to be physically equivalent, since a fibre corresponds to a gauge orbit. The space of equivalence classes of metric $[Lor(\mathcal{M})] := \{[g_{ab}], g_{ab} \in Lor(\mathcal{M})\}$ is also referred to as the *physical state space.*

Given any doublet $\left(g_{ab}, \mathfrak{R}_g^{(I)}\right)$, the action of $f_{\mathfrak{R}_g}$ will take that doublet to the *unique* and gauge-invariant reference frame representation of the metric $\left[\mathfrak{R}_g^{-1}\right]^* g_{ab}$.

This setup allows straightforward recovery of the analogue of equation (2) that demonstrate the gauge invariance of $f^*_{\mathfrak{R}_g} g_{ab}$

[14] According to the condition (3), the choice of a reference frame, seen as the choice of a section, is based on the imposition of a set of conditions that a models must satisfy. This procedure is analogous to what Gauss (1902) proposed in order to describe a surface embedded in an ambient space not from an external point of view, i.e. using the coordinates of the ambient space, but 'standing on the surface itself'. Such an embedded surface is *intrinsically* describable using some parametric equations. For example, a generic n-dimensional surface $\Sigma \subset N$, embedded in a generic $(n+1)$-dimensional Euclidean ambient space N (characterised by $n+1$ coordinates x^i), can be described by n parameters u^α with parametric equations of the type: $x^i(u^\alpha) = 0$. In our case, such equations take the form $F_{\mathcal{R}_g}(g_{ab}) = 0$, with $F_{\mathcal{R}_g} \in C^\infty(\mathcal{M})$ being a smooth and regular function.

[15] Given a general symmetry group, its gauge orbits are in general not one-dimensional. The representation of figure 1 is faithful only for one-dimensional groups, whose action can be depicted in a one-to-one manner along the one-dimensional orbits.

Proof. From the diagonal action of the diffeomorphisms d, we have:

$$f^*_{\mathfrak{R}_g} g_{ab} = f^*_{d^*\mathfrak{R}_g}\big((d^*g)_{ab}\big), \forall d \in Diff(\mathcal{M}). \tag{4}$$

Now, let me define

$$(g_{ab})_{F_{\mathfrak{R}_g}} := f^*_{\mathfrak{R}_g} g_{ab} \equiv \left[\mathfrak{R}_g^{-1}\right]^* g_{ab} \equiv g_{IJ}(\mathfrak{R}_g).$$

The previous two equations imply that:

$$\big((d^*g)_{ab}\big)_{F_{d^*\mathfrak{R}_g}} = f^*_{d^*\mathfrak{R}_g}\big((d^*g)_{ab}\big) = (g_{ab})_{F_{\mathfrak{R}_g}}.$$

□

This result establishes the uniqueness and gauge invariance of $g_{IJ}(\mathfrak{R}_g)$ across all equivalence classes of metrics and frames, as expected.[16]

The map $f_{\mathcal{R}_g}$ is clearly model-dependent, but for each equivalence class of models $[g_{ab}]$ every model in this equivalence class will give rise to *the same* relational observable $f^*_{\mathcal{R}_g} g_{ab}$, since $f^*_{\mathcal{R}_g} g_{ab} = f^*_{\mathcal{R}_{d^*g}} [d^*g]_{ab}$, as shown in equation (4).

This framework explicitly ensures gauge invariance, although it remains dependent on the choice of section or reference frame. Consequently, it is not frame-invariant.

As I will show in the next section, this is why a choice of a reference frame is commonly labelled as a *perspective* on an equivalence class, within what I call *the View from Nowhere*.

[16] $g_{IJ}(\mathfrak{R}_g)$ is also called a *dressed observable* (see e.g. Harlow and qiang Wu (2021)) and $f_{\mathfrak{R}_g}$ a *dressing function*. The reference frames $\mathfrak{R}_g$ are the '*clothes*'. I point out the presence of an exception to the *uniqueness* of gauge-invariant observables in representing the models of the theory, given the choice of a reference frame: the case where '*stabilisers*' are present (Gomes (2023a)). These are particular symmetries characteristic of so-called *reducible states*. For example, in a configuration space of *n* particles, we cannot *uniquely* fix the orientation for collinear configurations; these configurations are stabilised by an action of a rotation around the collinearity axis, also called the *isotropy group* (Wallace, 2022c, p.244). In GR, the automorphisms of the metric are stabilisers. Stabilisers can be present in case of reference frames taking periodic values over time, or in case of homogeneous models.

3 The View from Nowhere: Frame representations are perspectives on an equivalence class

Naturally, there is nothing inherently special about $\{\mathfrak{R}_g^{(I)}\}$; any reference frame that provides a specific mapping f for each isomorphism class suffices. The Kretschmann-Komar scalars are significant because of their *explicit* dynamical coupling to the metric. Crucially, the gauge invariance of the observable $g_{IJ}(\mathfrak{R}_g)$ depends on this dynamical coupling between the metric g_{ab} and the reference frame $\mathfrak{R}_g$.

In the following, to illustrate what I term the *View from Nowhere*, I examine an alternative type of reference frame. Specifically, I examine two distinct sets of GPS reference frames, which are identified as *dynamical reference frames* (**DRFs**) in Bamonti (2023), that is, reference frames dynamically coupled to the metric but without backreaction. For the present purposes, each GPS reference frame can be treated as a set of four scalar fields, corresponding to the proper time signals transmitted by four satellites. These signals, originating from a fixed initial point O, are transmitted to a target point P, effectively assigning four numerical values that 'coordinatise' P. For a detailed account of the construction of a GPS reference frame, see Rovelli (2002a).

Building on the framework of Bamonti and Gomes (2024a), consider that the two sets of satellites define a *red* frame $\{\phi_r^{(I)}\}$ and a *blue* frame $\{\phi_b^{(I)}\}$, respectively. These frames represent two distinct "physical parametrisations" over a shared spacetime region. Importantly, each reference frame is derived from a *distinct* physical system. In this context, the general-relativistic model can described by the tuple $\langle \mathcal{M}, g_{ab}, \phi_r^{(I)}, \phi_b^{(I)} \rangle$, and is supplemented by initial data $(\Delta^g, \Delta_g^{\phi_r}, \Delta_g^{\phi_b})$ which specify the initial conditions for the metric and the two frames. As in equation (1), both $\phi_r^{(I)}$ and $\phi_b^{(I)}$ constitute local diffeomorphisms $U \subset \mathcal{M} \rightarrow \mathbb{R}^4$.

Using the frame-bundle formalism introduced earlier, the model space is $M := (\mathrm{Lor}(\mathcal{M}) \cup \Phi)$, where $\Phi = \{\phi_r^{(I)}, \phi_b^{(I)}\}$ represents the space of GPS scalars defining the red and the blue frames. This model space is structured as a principal fiber bundle with the structure group $\mathrm{Diff}(\mathcal{M})$ and base manifold $[M]$. Here, $[M]$ comprises equivalence classes of metrics and reference frame, expressed as $\{[m] \in M\} = \{[g_{ab}] \in [\mathrm{Lor}(\mathcal{M})], [\phi_{r/b}^{(I)}] \in [\Phi]\}$.

If g_{ab} satisfies the condition described in Equation (3) for some F_{ϕ_r} (resp. F_{ϕ_b}), then any pair $(g_{ab}, \phi_r^{(I)})$ (resp. $(g_{ab}, \phi_b^{(I)})$), can be mapped into a *unique* reference frame representation of the metric. This mapping is achieved through the action of f_{ϕ_r} (resp. f_{ϕ_b}), yielding $(g_{ab})_{F_{\phi_r}} := f^*_{\phi_r} g_{ab}$, which is equivalent to the local gauge-invariant observable $[\phi_r^{-1}]^* g_{ab} := g_{IJ}(\phi_r)$. The same is for for ϕ_b. Refer to Figure 2.

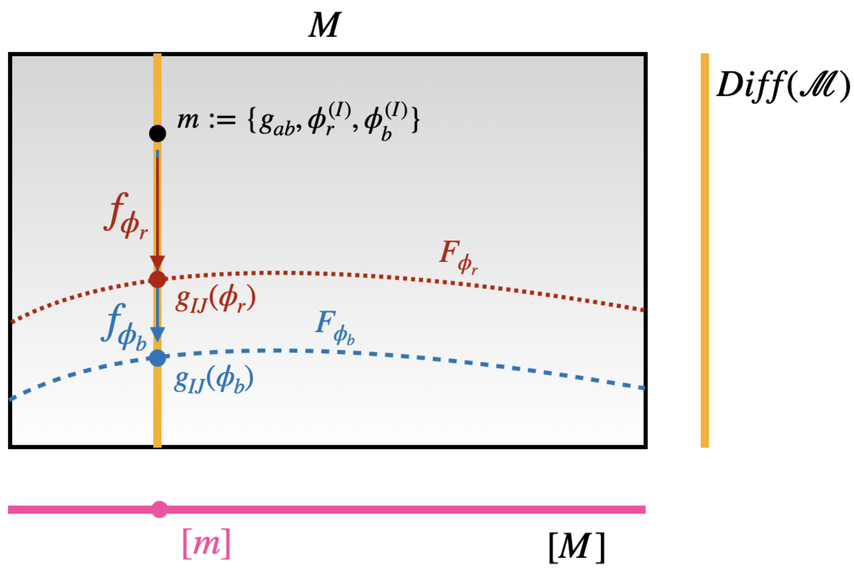

Figure 2: The space of models $M = \text{Lor}(\mathcal{M}) \cup \Phi$ with its gauge group Diff$(\mathcal{M})$. Each point corresponds to a triple $(g_{ab}, \phi_r^{(I)}, \phi_b^{(I)})$. A reference frame (either ϕ_r or ϕ_b) selects a *unique* representative $g_{IJ}(\phi_r)$ (or $g_{IJ}(\phi_b)$) for each fiber $\mathbb{F}_m$. This is achieved through the projection map f_{ϕ_r} (or f_{ϕ_b}). The map projects a model within a fiber onto the intersection of the fiber with a chosen reference frame, represented by the 'level surface' F_{ϕ_r} (or F_{ϕ_b}).

As per Equation (2), $g_{IJ}(\phi_r)$ and $g_{IJ}(\phi_b)$ are gauge-invariant, relational observables that represent distinct physical scenarios. Nonetheless, they are frequently interpreted as mere *perspectives* on a shared equivalence class $[g_{ab}]$ of isometric metrics. This equivalence class is regarded as the sole structure with 'ontological significance', which means that it is considered the fundamental structure underlying physical reality. As shown in Table 1, $[g_{ab}]$ is frame-free, spatiotemporally implicit, and gauge-invariant. This interpretation constitutes what I call:

The View from Nowhere: Frame representations are perspectives on an equivalence class of models implicitly defined without reference frames. This could also be termed a "view from no-reference frame."[17]

[17]This interpretation differs from that of Adlam and Rovelli (2023), who associate a View from Nowhere with observer-*independent* facts, equating observers to reference frames. Here, following Wallace (2019), I assert that the View from Nowhere implies the existence of frame-*free* facts, distinguishing between observer-independence and observer-freedom.

Advocates of this view argue that physical reality fundamentally consists of abstract equivalence classes, existing independently of specific reference frame representations. These representations, which vary across spatiotemporal frames, are simply different ways of characterizing the same invariant structure. Consequently, transformations between reference frames are interpreted as notational changes rather than changes to the underlying reality.

Drawing from Kantian ontology (Kant, 1998), I differentiate between *phenomenal reality*, —measurable phenomena as they appear to observers— and *noumenal reality*, which represents the ultimate essence of reality. Within this framework, frame representations serve as phenomenal depictions of an implicit underlying reality, expressed through equivalence classes that cannot be explicitly characterised in spatiotemporal terms. In this terminology, the View from Nowhere *presupposes* the existence of a *noumenal reality* for which different spatiotemporal, phenomenological realities can be provided.

While theoretically consistent, the View from Nowhere presents challenges for experimental practice. This view relies on an abstract, frame-free ontology that does not directly correspond to the relational nature of empirical data, which inherently depend on specific reference frames. As a result, translating theoretical constructs into measurable phenomena becomes a significant obstacle.

The relational character of empirical measurements has been widely acknowledged throughout the literature. Observations rely on the relationships established between the system under investigation and the reference frame within which measurements are conducted. For instance, Anderson emphasises that all measurements fundamentally involve comparisons between different physical systems (Anderson, 1967, p.128). Similarly, Rovelli (Rovelli, 1991, p.298) and Landau (Landau and Lifshitz, 1987, p.1) stress the indispensable role of reference frames in any measurement process. This reliance on reference frames underscores the difficulty of reconciling the abstract, frame-free ontology of the View from Nowhere with practical empirical methodologies.[18]

This operational stance aligns with Einstein's original articulation of the point-coincidence argument, where he asserted that the physical content of a theory lies in the spacetime coincidences

[18] Additional support for the relational nature of empirical data comes from the "Unobservability Thesis," which posits that symmetry-related models of a system are empirically indistinguishable (Wallace, 2022c). Similarly, discussions on empirical (in)equivalence argue that explicit inclusion of observers leads to an 'immanent' conception of empirical distinctions, where models differ only if field configurations exhibit relational differences (Pooley and Read, 2021).

of material points (see Giovanelli (2021)). Specifically, Einstein highlighted that spacetime verifications invariably amount to determining such coincidences Einstein (1916) and that physical experiences are always assessments of point coincidences Einstein (1919). These arguments reinforce the relational nature of observations and challenge the View from Nowhere's reliance on frame-free ontology.

Thus, any observable quantity, being both measurable and predictable, must be gauge-invariant and relational. By contrast, assigning ontological significance solely to abstract equivalence classes introduces significant challenges for observational verification, raising practical challenges for experimental validation. To address these issues, advocates of the View from Nowhere must go beyond asserting frame-free gauge-invariant content and provide practical guidance for experiment-based predictions—a daunting task, in my opinion.

The philosophical foundations of the View from Nowhere: Sophistication

Despite criticisms, the View from Nowhere maintains a substantial following. This is not surprising, since its conceptual foundations rest on what is known as the sophisticated approach to symmetries, or simply *Sophistication* about symmetries. This approach contrasts with *Eliminativism*, as it seeks to preserve symmetry-related structures rather than eliminate them entirely. For a more extensive analysis of the various positions on symmetries, see, e.g., Dewar (2019) and Gomes (2023b).

Eliminativism argues that a theory must be formulated solely in terms of symmetry-invariant objects such as equivalence classes. This eliminates individual symmetry-related models of the theory, thereby eradicating representational redundancy.

In contrast, *Sophistication* rejects Eliminativism while embracing a structuralist stance. It posits that symmetries uncover an underlying invariant structure, which holds genuine ontological significance. Unlike Eliminativism, Sophistication allows symmetry-related models to coexist without removing them from the formalism. Jacobs (2021), drawing on the Erlangen Programme (Klein, 1893), characterises Sophistication as a *symmetry-first approach*, also known as the *external approach* (Dewar, 2019, p.502).

Moreover, Dewar argues that, Sophistication, unlike Eliminativism, does not require an intrinsic characterisation of $[M]$ for an ontological commitment to equivalence classes alone. However, Martens and Read (2020) have criticised this method of defining invariant structures — defined as the *interpretational approach* by Møller-Nielsen (2017) — for failing to ensure a *perspicuous* understanding of the shared ontology underlying various models.

In response to this critique, Gomes (2024a) defends the use of reference frames (which he terms representational conventions), formalised through a projection operator $f_\sigma : M \to M$ on the fiber bundle M. This procedure provides a *perspicuous*, yet choice-dependent, characterisation of $[M]$. The adoption of f_σ instead of the section map $\sigma : [M] \to M$ aligns with the external approach's claim that intrinsic parameterisation of elements $[m] \in [M]$ is unnecessary. Furthermore, Gomes' approach integrates the external, symmetry-first perspective with the *motivational approach*, shielding Sophistication from accusations of being "cheap" (Martens and Read (2020); Belot (2017)). *The motivational approach*, as defined by Møller-Nielsen (2017), asserts that two symmetry-related models can only be considered physically equivalent if a *perspicuous* characterisation of their shared ontology is provided. According to Gomes, the projection operator serves precisely this purpose.

I argue that Gomes' approach, while insightful, is ultimately insufficient. Even if one characterises each equivalence class by selecting a 'representative' (a relational gauge-invariant observable), this does not resolve the underlying ontological commitment to the equivalence classes themselves. Designating a representative only provides a single *perspective* on the broader structure, leaving the full ontology of the theory incompletely addressed.

Loss of information

I have already expressed many of my qualms about the View from Nowhere, and in the next section I will offer an alternative on how to interpret the formalism of relational observables. Before doing so, however, I want to dwell on a further problem related to the View from Nowhere: namely the loss of physical information.[19] It can be said that, within this view, different choices of reference frames can be conceptualised as 'windows of knowledge that provide partial views of a shared

[19]This loss is exemplified by what Tong says about the choice of a gauge:

> The [gauge] redundancy allows us to make manifest the properties of quantum field theories, such as unitarity, locality, and Lorentz invariance, that we feel are vital for any fundamental theory of physics but which teeter on the verge of incompatibility. If we try to remove the redundancy by fixing some specific gauge, some of these properties will be brought into focus, while others will retreat into murk. By retaining the redundancy, we can flit between descriptions as is our want, keeping whichever property we most cherish in clear sight. (Tong, 2018, p.1)

invariant structure', available to an observer (see Adlam (2024) on how to schematise a conscious observer in a diff-invariant theory such as GR). Accordingly, an observer can adjust her perspective to explore specific aspects of this invariant structure, effectively selecting one reference frame over another based on her investigative focus.

However, this approach implies a loss of the complete, 'absolute' information contained within the ontologically fundamental structure, which is defined by the equivalence class.

This idea also resonates with Einstein (1917)'s assertion that " [. . .]a definite choice of the system of reference [. . .] is contrary to the spirit of the relativity principle." Similarly, (Adlam, 2024, p.9) argues that "diffeomorphism invariance could finally be broken by the observer herself." Geng (2024) also echoes this viewpoint.

Selecting a specific reference frame, such as through gauge-fixing, highlights certain properties of the physical system while concealing others. It is only by retaining redundancy and adopting a perspective from nowhere that the entirety of the physical landscape (the equivalence class) be fully represented. The View from Nowhere aspires to achieve this comprehensive perspective, though it does so at the expense of direct empirical applicability.

This critique of the View from Nowhere highlights significant conceptual and practical challenges, though further exploration may reveal additional nuances. In the following section, I will explore how to provide a *perspicuous* characterisation of the theory's invariant ontology without resorting to equivalence classes of symmetry-related models, as the sophisticated approach advocates. I shall refer to this alternative perspective as the View from Everywhere.

4 The View from Everywhere: Frame representations are all that exist

Returning to the example of the two GPS reference frames introduced earlier, an alternative interpretation of the two local observables $g_{IJ}(\phi_b)$ and $g_{IJ}(\phi_r)$ can be proposed. Rather than treating frame representations as perspectives on an abstract equivalence class, this alternative asserts that *each member* of the collection of observables $\{g_{IJ}(\phi_b), g_{IJ}(\phi_r), \dots\}$ (where the ellipsis indicates additional reference frames and related observables) constitutes *all* that fundamentally exists.

This perspective embodies what I term:

The View from Everywhere: *each* frame representation is all that ultimately exists. It may also be conceptualised as a "view from every reference frame", emphasising the primacy of local, relational observables.

In Bamonti and Gomes (2024b), a map $\mathbf{m}$ called *external diffeomorphism* is introduced to relate the two frames $\{\phi_r^{(I)}\}$ and $\{\phi_b^{(I)}\}$, functioning analogously to a coordinate transformation. Unlike an 'ordinary diffeomorphism', an external diffeomorphism acts *directly* on the already constructed local, gauge-invariant observables, changing frames and getting us to a different and new observable.

By redefining $\phi_r^{(I)} := X_r^I$ and $\phi_b^{(I)} := X_b^{I'}$, the gauge-invariant observables $g_{IJ}(\phi_r) := g_{IJ}(X_r^I)$ and $g_{IJ}(\phi_b) := g_{I'J'}(X_b^{I'})$ are connected via the map $\mathbf{m}$, which operates as follows:

$$\mathbf{m} : g_{IJ}(X_r^I) \to g_{I'J'}(X_b^{I'}) = \frac{\partial X_r^I}{\partial X_b^{I'}} \frac{\partial X_r^J}{\partial X_b^{J'}} g_{IJ}(X_r^I). \tag{5}$$

Clearly, this represents a passive diffeomorphism transformation.[20] This shows that in GR, local gauge-invariant observables are *covariant* under frame transformations[21], so the introduction of a gauge choice (in the form of a choice of reference frame) does not spoil either the gauge invariance or the covariance of the theory.

It is important to note that while there can indeed be *frame-independent* observables, these quantities, however, would inherently be non-local in nature (see Table 1).

While the map $\mathbf{m}$ provides a 'shared vocabulary' for translating between two distinct reference frame representations, it is important to emphasise that these represent separate and *fully-fledged* physical situations.[22] Consequently, they are not two *perspectives* of a *shared, total* physical state as

[20]Due to the one-to-one correspondence between active and passive diffeomorphisms, from the active perspective, the relationship between $g_{IJ}(\phi_r)$ and $g_{IJ}(\phi_b)$ can be interpreted as the external diffeomorphism $\mathbf{d} := \phi_r^{-1} \circ \mathbf{m} \circ \phi_r$, or equivalently $\mathbf{d} := \phi_b \circ \mathbf{m}^{-1} \circ \phi_b^{-1}$.

[21]Pitts (2022) refers to covariance of observables relative to coordinate systems. Here, I propose to extend this notion to encompass reference frames.

[22]In (Belot, 2017, p.954)'s terminology, $\mathbf{m}$ is a "physical symmetry"—an isomorphism linking solutions that represent distinct "possibilia"—as opposed to a "gauge symmetry," which relates solutions that cannot be taken to represent distinct physical states.

proposed in the View from Nowhere. Unlike the View from Nowhere, the View from Everywhere does not require the existence of such a shared state. Instead, *each* gauge-invariant observable represents an independent and self-contained physical reality. Under this framework, we do not require any invariant, frame-free structure in our ontology. Instead, the focus shifts to a theory of frame-dependent yet gauge-invariant objects.

Importantly, the absence of a shared, total reality in this framework—replaced by a collection of local, frame-dependent realities—does not imply a lack of coherence. *Fragmentation does not imply incoherence.* The different physical situations represented by the gauge-invariant observables $g_{IJ}(\phi_r)$ and $g_{IJ}(\phi_b)$ remain interconnected through external diffeomorphisms $\mathbf{m}$.

The map $\mathbf{m}$ also protects us from potential accusations of *solipsism* (see (Adlam and Rovelli, 2023, sec.6) and the references therein for a discussion in the context of relational quantum mechanics). Each observer—understood as being associated with a reference frame—is not isolated in their representation of reality but can communicate with all other observers. Through $\mathbf{m}$, observers can translate their frame-specific representations into those of others. Importantly, this does not mean that each observer accesses merely a fragment, a perspective of a larger, overarching whole. Instead, every perspective constitutes a complete and self-consistent depiction of reality.

Also, the existence of the external diffeomorphism $\mathbf{m}$ enables advocates of the "View from Everywhere" to define an equivalence class $[g_{IJ}] := \{g_{IJ}(\phi_r), g_{IJ}(\phi_b), \dots\}$, which differs fundamentally from the equivalence class $[g_{ab}] := \{g_{ab}, (d^*g)_{ab}, \dots\}$ used in the View from Nowhere. Unlike the latter, the equivalence class $[g_{IJ}]$ within the View from Everywhere *supervenes* on the ensemble of *all* the frame-dependent quantities. Each of these quantities form the a *bona-fide* physical reality, rather than existing as perspectives of an abstract, frame-free structure. Coherently, $[g_{IJ}]$ is a frame-independent object, as it is expressed across *all possible* reference frames. So differently from $[g_{ab}]$, it is not a frame-free object. In *formal terms*: the View from Everywhere retains a one-to-one correspondence between the equivalence class $[g_{IJ}]$ and the orbit $O_g := \{g_{IJ}(\phi_r), g_{IJ}(\phi_b), \cdots\}$. However, unlike the View from Nowhere, $[g_{IJ}]$ in the View from Everywhere does not exist independently of the frame-specific representations within the space of models. Essentially, $[g_{IJ}]$ and O_g *coincide*. See Figure 3.

If for the View from Nowhere the equivalence class $[g_{ab}]$ represented a *shared ontology*, for the View from Everywhere, the equivalence class $[g_{IJ}]$ only represents the presence of a

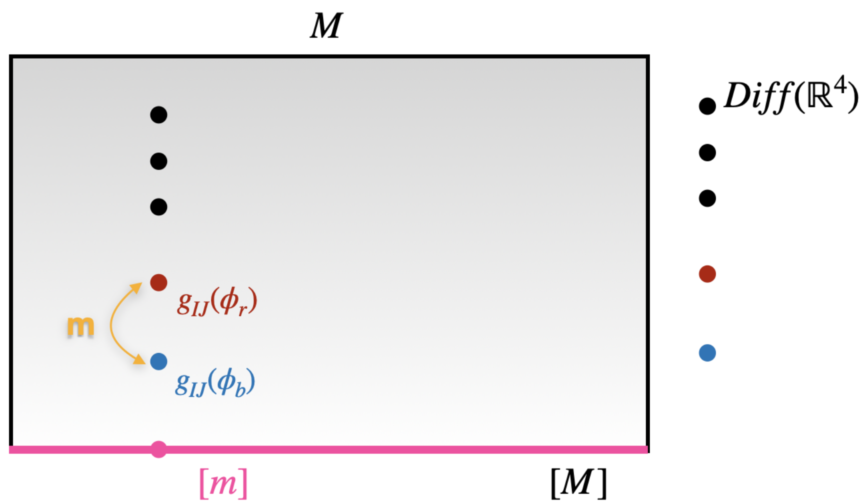

Figure 3: The set $[M]$ of equivalence classes is part of the space of models itself. Moreover, it is the set of relational observables that can be understood as a fiber, generated by the group $Diff(\mathbb{R}^4)$, whose group elements are external diffeomorphisms **m**.

shared vocabulary. This distinction underscores the divergence between the two views: the View from Everywhere rejects the existence of a frame-free, *ontologically independent* structure, focusing instead on the relational and frame-specific nature of observables. Consequently, the term 'perspective' becomes problematic in this context, as it implies an underlying reality that can be described from multiple viewpoints—an assumption the View from Everywhere does not adopt.

What conception of reality emerges from this framework? Within the View from Everywhere, *each* of the frame-dependent physical situations constitutes a fully-fledged reality. The collection of such realities constitutes what I call *Relality*. The concept of Relality is intriguing and deserves to be analysed further. Importabtly, this concept helps me to emphasise that reality is fundamentally local and relational.

Drawing on the Kantian perspective used to interpret the View from Nowhere, I argue that the View from Everywhere fundamentally rejects the notion of a shared, implicit noumenal reality underlying its phenomenological manifestations. According to the View from Everywhere, there is no 'hidden' structure beyond these frame-specific representations; *each* gauge-invariant quantity constitutes the entirety of what fundamentally exists. Accordingly, the two observables $g_{IJ}(\phi_r)$ and $g_{IJ}(\phi_b)$ do not describe two distinct phenomenal perspectives of a shared, ontologically independent noumenal reality represented by $[g_{ab}]$. Instead, *each* constitutes a reality and *there* *is nothing else*. This is because the concept of Relality, formalised by $[g_{IJ}]$, does *not* represent a shared ontology. Its utility lies only in ensuring the inter-translatability of each reality. This supports the abandonment of the concept of ‘perspective’.

In this section, I argue that the interpretive framework of the View from Everywhere challenges the core assumptions of the Sophistication approach. Specifically, I will demonstrate that the View from Everywhere offers greater ontological parsimony—minimising unnecessary metaphysical commitments—and provides a clearer, more *perspicuous* characterisation of the ontology underlying relational observables. Consequently, I contend that Sophistication is neither the ultimate nor the most effective framework for interpreting relational observables.

Beyond Sophistication

As already stressed, the Sophistication approach posits that the fundamental description of physical reality should rely on equivalence classes. The View from Everywhere proves that this assumption is unnecessary. Gauge-invariant relational observables, such as $g_{IJ}(\phi_r)$ and $g_{IJ}(\phi_b)$, represent distinct, *fully-fledged* physical scenarios, leaving no basis to hypothesise the existence of an additional ’hidden’ structure beyond them. This interpretation aligns with a principle of ”ontological parsimony”, which I sustain. The View from Everywhere, being ontologically more conservative, posits no ‘entities’ beyond the realities expressible within reference frames.

As previously discussed, adopting Sophistication while supporting a motivational approach and offering a *perspicuous* characterisation of the ontology presents significant challenges. Among the proposals, Gomes’ motivational approach shows promise but ultimately falls short within the Sophistication framework. However, Gomes’ motivational approach aligns naturally with the View from Everywhere. By eliminating the need for a shared ontology based on equivalence classes, the very construction of the gauge-invariant observables constituting the fundamental ontology inherently provides a *perspicuous* characterisation of the ontology.

This claim raises a delicate question: How can Gomes’ approach, which employs projection maps onto fibres of isomorphic, gauge-variant models, function within the framework of the View from Everywhere? After all, I have argued that the only relevant fibre in this framework consists of gauge-invariant observables connected by external diffeomorphisms (see Figure 3). At first glance, it appears that the View from Everywhere, if not based on Sophistication, instead relies on

Eliminativism, rendering Gomes' proposal inapplicable. However, this conclusion is incorrect. The View from Everywhere accommodates the formal construction of frame representations within the fibre bundle formalism, demonstrating the continued relevance of Gomes' insights. For example, a frame representation, such as $g_{IJ}(\phi_r)$, can still be derived as a projection of a fibre onto a section. Even if within the View from Everywhere, the ontology is characterised by quantities that are independent of the structures distinguishing various isomorphic, gauge-variant models, the construction of these quantities *necessitates* the use of non-invariant objects. This fact lies at the heart of the relational observables strategy, where gauge-*variant* quantities serve as *handles* through which other gauge-variant quantities are coupled, to form gauge-invariant quantities (see Rovelli (2014)).

Therefore, supporting the View from Nowhere does not imply the *removal* of redundant gauge degrees of freedom. Rather, it only involves attributing ontological importance to the gauge-invariant observables.

No loss of information

Previously, I outlined one advantage of the View from Everywhere: its ability to provide a *perspicuous* characterisation of the ontology of the theory, in line with a motivational approach. In this concluding paragraph, I emphasise an additional advantage: it resolves the issue of physical information loss and the problem of diffeomorphic symmetry breaking, both of which stem from the choice of a particular reference frame (or, equivalently, gauge fixing).

First, the breaking of the diffeomorphic freedom of theory is precluded by the existence of the external diffeomorphism **m**. This map relates different reference frame choices[23], ensuring GR to remain **m**-covariant (see also Bamonti and Gomes (2024a)).

Second, the notion of Relality implies that *all* the available information resides within *each* frame. Consequently, there is no 'total' information that could be lost when a specific reference frame is selected. This may also alleviate the concerns raised in Wallace (2024) that the choice of certain reference frames (some gauge-fixings) does not preclude the physical features of the system from varying under a gauge transformation, leading to a loss of genuine information and casting

[23]**m** serves as the analogue of the transition map between sections of a principal bundle, given by $\mathbf{t}_{\sigma\sigma'}(\varphi) = f_{\sigma'}(\varphi)^{-1} f_{\sigma}(\varphi)$ (see Gomes (2024a)).

doubt on whether they can really be classified as gauge-fixing at all (see 'The Incompleteness Reason', ivi, p.13).[24]

Before concluding, I wish to highlight another advantage of the "View from Everywhere" concerning the choice of reference frame. The choice is entirely arbitrary, raising the question of what guides such a choice. *In the context of the View from Nowhere*, reference frame selection is typically driven by pragmatic considerations, aimed at providing a convenient description of an objective, overarching physical reality. These motivations are largely '*conventional*,' reflecting a preference for ease of description rather than any deeper ontological commitment. In fact, the choice of reference frame, by definition, merely offers a conventional, *perspectival* description.[25] In contrast, *in the context of the View from Everywhere*, a choice of reference frame constitutes an *empirical* choice, rather than a conventional one. This is because we cannot conventionally choose one or another reference frame that represents the 'same', 'true' physical situation in the most helpful way for the purpose at hand. A different choice is in all respects a *different reality*.

Finally, the View from Everywhere also alleviates the problem whereby the validity of a choice of reference frame cannot be empirically tested. In fact, every measurement is always made within a reference frame, i.e. to make measurements, a reference frame must necessarily be set. Thus, we have no 'meta-empirical ground' (that is, a frame-free empirical ground) to compare the various possible reference frames. Within the View from Nowhere, this *is* a problem, since each choice of reference frame is comparable to a perspective and it makes sense to ask which description is 'the best', from a pragmatic or fundamental point of view. The advocate of the View from Everywhere, on the other hand, might claim that there is no need to test the validity of the choice of reference

[24] To be precise, Wallace studies the so-called 'unitary gauge' in electrodynamics. I argue that this choice of gauge corresponds to the use of *uncoupled reference frames*. In other words, the physical features that change are features of the physical system considered as *isolated* from the environment (Wallace, 2022a,b). This isolation procedure coincides with the dynamic uncoupling of the reference frame. The ''loss of genuine information'' referred to by Wallace, therefore, is *not* really genuine because it is a consequence of this approximate procedure. Within the View from Nowhere, on the other hand, there is the loss of *bona-fide genuine* information as a result of the use of coupled reference frames, which identify distinct gauge-invariant observables. The View from Nowhere alleviates this, more serious, problem.

[25] A contrasting argument is discussed in (Gomes and Butterfield, 2024, sec.3). In the context of electromagnetism, the authors propose that "a choice of gauge need not be a matter of calculational convenience for some specific problem or class of problems, but can be related to a physically natural and general splitting of the electric field." However, the authors also note that a physically defined gauge choice (e.g., the Coulomb gauge, which splits the electric field into radiative and Coulombic parts, with the latter determined by the instantaneous charge distribution) is still "*non-mandatory*." It corresponds to a particular choice of electric field decomposition. Thus, ultimately, it remains, in my view, a "*convention*."

frame, since any choice of reference frame is inherently 'the best' or 'the most fundamental', as the only available and existing reality.

5 Conclusion

This paper has employed the fiber bundle framework to examine the role of reference frames and relational observables in GR, highlighting the philosophical and practical consequences of two contrasting paradigms: the View from Nowhere and the View from Everywhere. Below, I summarise the key findings of the paper and their broader implications.

In Section 2, I used the fiber-bundle formalism to discuss reference frames and relational observables in GR. This approach defines the space of models as a principal bundle and introduces gauge orbits to describe symmetries within the theory. Reference frames, acting as section maps, facilitate the construction of gauge-invariant observables. This formalism elucidates the relationship between the choice of a reference frame and the choice of a gauge-fixing.

In Section 3, I introduced the *View from Nowhere*, which conceptualises reference frame representations as *perspectives* on an underlying invariant equivalence class of isomorphic models. This perspective, informed by the Sophistication approach, posits that the fundamental ontology of GR resides in gauge-invariant equivalence classes, independent of specific frame representations. While theoretically robust, this perspective encounters significant challenges in aligning with empirical practice, as it assumes the existence of an abstract, frame-free reality that is not directly observable.

In Section 4, I introduced the *View from Everywhere*. Contrary to the View from Nowhere, it rejects the presumption of an underlying equivalence class to be given ontological relevance. Instead it asserts that frame-dependent, local relational observables constitute all that fundamentally exists. To capture this viewpoint, the concepts of *Relality* and of external diffeomorphism $\mathbf{m}$ were introduced, emphasising the fragmented yet coherent nature of frame-dependent realities. By adhering to the principle of ontological parsimony, the View from Everywhere avoids unnecessary metaphysical commitments to frame-free structures and naturally provides a *perspicuous* characterisation of the ontology, with implications for experimental design and theoretical consistency.

The philosophical implications of adopting the View from Everywhere warrant further examination. This includes analyising concepts like *perspectivalism* and *objectivity* within GR. A deeper analysis of the concept of '*Relality*' may yield valuable insights in this regard. Additionally, investigating the role of external diffeomorphisms within the context of quantum reference frames offers a promising direction for future research.

In conclusion, this paper has examined the complex interplay between reference frames, gauge symmetries, and ontology in GR. By contrasting the View from Nowhere and the View from Everywhere, I have sought to deepen our understanding of the interplay between theory, empirical practice, and philosophical interpretation. This analysis underscores the significance of reference frames in shaping our understanding of physical reality and highlights the need for further investigation into their foundational role in physics.

Acknowledgement

I thank Henrique Gomes for useful discussions. I thank S. for inspiring me to conceive the View from Everywhere.

References

Adlam, E. (2024). How do we observe relational observables?

Adlam, E. and C. Rovelli (2023). Information is physical: Cross-perspective links in relational quantum mechanics. *Philosophy of Physics 1*(1).

Anderson, J. L. (1967, May). *Principles of relativity physics*. San Diego, CA: Academic Press.

Bamonti, N. (2023, January). What is a reference frame in general relativity? *forthcoming*.

Bamonti, N. and H. Gomes (2024a). The hole argument for reference frames.

Bamonti, N. and H. Gomes (2024b). What reference frames teach us. part i: About symmetry principles and observability.

Belot, G. (2017, April). Fifty million elvis fans can't be wrong. *Noûs 52*(4), 946–981.

Berghofer, P., J. François, S. Friederich, H. Gomes, G. Hetzroni, A. Maas, and R. Sondenheimer (2023). *Gauge Symmetries, Symmetry Breaking, and Gauge-Invariant Approaches*. Cambridge University Press.

Bergmann, P. and A. Komar (1962). Status report on the quantization of the gravitational field. In *Recent Developments in General Relativity*, pp. 31–46. Pergamon Press.

Bergmann, P. G. and A. B. Komar (1960). Poisson brackets between locally defined observables in general relativity. *Physical Review Letters 4*(8), 432.

Dewar, N. (2019). Sophistication about symmetries. *British Journal for the Philosophy of Science 70*(2), 485–521.

Dirac, P. A. M. (1964). *Lectures on quantum mechanics*. Dover Publications.

Dittrich, B. (2006, October). Partial and complete observables for canonical general relativity. *Classical and Quantum Gravity 23*(22), 6155–6184.

Dittrich, B. (2007, August). Partial and complete observables for hamiltonian constrained systems. *General Relativity and Gravitation 39*(11), 1891–1927.

Earman, J. (2004). Laws, symmetry, and symmetry breaking: Invariance, conservation principles, and objectivity. *Philosophy of Science 71*(5), 1227–1241.

Einstein, A. (1916). Hamilton's Principle and the General Theory of Relativity. *Sitzungsber. Preuss. Akad. Wiss. Berlin (Math. Phys.) 1916*, 1111–1116.

Einstein, A. (1917). Cosmological Considerations in the General Theory of Relativity. *Sitzungsber. Preuss. Akad. Wiss. Berlin (Math. Phys.) 1917*, 142–152.

Einstein, A. (1919). Lecture notes for course on general relativity at the university of berlin. *CPAE, Vol 7, Doc.19*.

Einstein, A., H. Gutfreund, and J. Renn (2015). *Relativity: The Special & the General Theory*. Princeton University Press.

Gary, M. and S. B. Giddings (2007, May). Relational observables in 2d quantum gravity. *Physical Review D 75*(10).

Gauss, C. (1902). General investigations of curved surfaces of 1827 and 1825. *The Princeton university library*.

Geng, H. (2024). Quantum rods and clock in a gravitational universe.

Giacomini, F. et al. (2019, January). Quantum mechanics and the covariance of physical laws in quantum reference frames. *Nature Communications 10*(1).

Giovanelli, M. (2021, May). Nothing but coincidences: the point-coincidence and einstein's struggle with the meaning of coordinates in physics. *European Journal for Philosophy of Science 11*(2).

Gomes, H. (2023a). Same-diff? conceptual similarities between gauge transformations and diffeomorphisms. *forthcoming*.

Gomes, H. (2023b). Understanding the symmetries of physics. *forthcoming*.

Gomes, H. (2024a). Representational conventions and invariant structure.

Gomes, H. (2024b, October). Representational schemes for theories with symmetry.

Gomes, H. and J. Butterfield (2024). How to choose a gauge? the case of hamiltonian electromagnetism. *Erkenntnis 89*(4), 1581–1615.

Gribov, V. (1978, June). Quantization of non-abelian gauge theories. *Nuclear Physics B 139*(1–2), 1–19.

Harlow, D. and J. qiang Wu (2021). Algebra of diffeomorphism-invariant observables in jackiw-teitelboim gravity. *Journal of High Energy Physics 2022*.

Healey, R. (2007). *Gauging What's Real:The Conceptual Foundations of Contemporary Gauge Theories*. OUP Oxford.

Henneaux, M. and C. Teitelboim (1994, August). *Quantization of gauge systems*. Princeton, NJ: Princeton University Press.

Jacobs, C. (2021). *Symmetries as a Guide to the Structure of Physical Quantities*. University of Oxford.

Kabel, V., A.-C. de la Hamette, L. Apadula, C. Cepollaro, H. Gomes, J. Butterfield, and C. Brukner (2024). Identification is pointless: Quantum reference frames, localisation of events, and the quantum hole argument.

Kant, I. (1998). *Critique of Pure Reason*. Oeuvre. Cambridge University Press.

Klein, F. (1893). Vergleichende betrachtungen über neuere geometrische forschungen. *Mathematische Annalen 43*, 63–100.

Komar, A. (1958, Aug). Construction of a complete set of independent observables in the general theory of relativity. *Phys. Rev. 111*, 1182–1187.

Kretschmann, E. (1918, January). Über den physikalischen sinn der relativitätspostulate, a. einsteins neue und seine ursprüngliche relativitätstheorie. *Annalen der Physik 358*(16), 575–614.

Landau, L. D. and E. M. Lifshitz (1987, January). *The classical theory of fields* (4 ed.). Oxford, England: Butterworth-Heinemann.

Leplin, J. (1975, February). The concept of an ad hoc hypothesis. *Studies in History and Philosophy of Science Part A 5*(4), 309–345.

Martens, N. C. M. and J. Read (2020, May). Sophistry about symmetries? *Synthese 199*(1–2), 315–344.

Massimi, M. (2022, October). *Perspectival realism*. Oxford Studies in Philosophy of Science. New York, NY: Oxford University Press.

Møller-Nielsen, T. (2017). Invariance, interpretation, and motivation. *Philosophy of Science 84*(5), 1253–1264.

Pitts, J. B. (2022, October). Peter bergmann on observables in hamiltonian general relativity: A historical-critical investigation. *Studies in History and Philosophy of Science 95*, 1–27.

Pooley, O. and J. A. M. Read (2021). On the mathematics and metaphysics of the hole argument. *The British Journal for the Philosophy of Science 0*(ja), null.

Rovelli, C. (1991, February). What is observable in classical and quantum gravity? *Classical and Quantum Gravity 8*(2), 297–316.

Rovelli, C. (2002a, Jan). Gps observables in general relativity. *Phys. Rev. D 65*, 044017.

Rovelli, C. (2002b, jun). Partial observables. *Physical Review D 65*(12).

Rovelli, C. (2006). *Chapter 2: The Disappearance of Space and Time*, pp. 25–36. Elsevier.

Rovelli, C. (2014, January). Why gauge? *Foundations of Physics 44*(1), 91–104.

Rovelli, C. and M. Gaul (2000). Loop quantum gravity and the meaning of diffeomorphism invariance. In *Lecture Notes in Physics*, pp. 277–324. Springer Berlin Heidelberg.

Rovelli, C. and F. Vidotto (2015). *Covariant Loop Quantum Gravity: An Elementary Introduction to Quantum Gravity and Spinfoam Theory*. Cambridge University Press.

Tong, D. (2018). Lectures on gauge theory. *http://www.damtp.cam.ac.uk/user/tong/gaugetheory.html*.

Vanrietvelde, A., P. A. Hoehn, F. Giacomini, and E. Castro-Ruiz (2020, January). A change of perspective: switching quantum reference frames via a perspective-neutral framework. *Quantum 4*, 225.

Wallace, D. (2019, August). Who's afraid of coordinate systems? an essay on representation of spacetime structure. *Studies in History and Philosophy of Science Part B: Studies in History and Philosophy of Modern Physics 67*, 125–136.

Wallace, D. (2022a, April). Isolated systems and their symmetries, part i: General framework and particle-mechanics examples. *Studies in History and Philosophy of Science 92*, 239–248.

Wallace, D. (2022b). Isolated systems and their symmetries, part ii: Local and global symmetries of field theories. *Studies in History and Philosophy of Science 92*, 249–259.

Wallace, D. (2022c, August). *Observability, Redundancy, and Modality for Dynamical Symmetry Transformations*, pp. 322–353. Cambridge University Press.

Wallace, D. (2024). Gauge invariance through gauge fixing.

Weatherall, J. O. (2016). Understanding gauge. *Philosophy of Science 83*(5), 1039–1049.