started to further our understanding of the interplay between different areas of psychological functioning, such as cognition, emotion, and motivation, as well as our insight into ecologically relevant and complex constructs such as wisdom and art of life (e.g., Baltes et al. 1998, Labouvie-Vief 1994, Staudinger 1999).

Needless to say, a number of issues remain to be explored. Lifespan psychologists, for instance, have only started to integrate the study of functional aspects of human development with the investigation of microgenetic processes. Projects along these lines have been to ask which are the regulatory processes that allow the aging person to maintain comparatively high levels of well-being and fulfilling lives (e.g., Baltes and Baltes 1990, Brandtstädter and Greve 1994, Heckhausen and Schulz 1995, Staudinger et al. 1995). Within the field of cognitive aging more and more research is oriented towards understanding the micro-analytic processes that may underlie the age-related decline in the cognitive mechanics.

Another issue that needs further theoretical and empirical work is the study of the ecology of human development. There is too little systematic work on classifying environments in their effects on human development. And finally the dynamic systems approach borrowed from physics has not yet been explored to its fullest when it comes to understanding human development.

Lifespan psychology does not prescribe the goals of development. Rather, it has taken on the mission to accumulate and disseminate knowledge about which processes and characteristics contribute under which circumstances to the optimization of development. Eventually, it will be this kind of knowledge that every individual may use to compose his or her life in a fulfilling manner.

*See also*: Developmental Psychology; Lifespan Development: Evolutionary Perspectives; Lifespan Theories of Cognitive Development; Plasticity in Human Behavior across the Lifespan

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U. M. Staudinger

# Lifespan Theories of Cognitive Development

Most lifespan theories of cognitive development (LTCD) provide an integrative framework for the description, explanation, and optimization of cognitive development across different functional domains and age periods. Arguably the first LTCD dates back to Johann Nicolaus Tetens (1736–1807), a philosopher and psychologist of the Enlightenment era. Tetens (1777) noted that well-trained skills are less likely to decline with advancing adult age than the basic abilities underlying their acquisition, and this observation and conceptual distinctions related to it have remained at the heart of LTCD.

## *1. Central Assumptions of LTCD*

Most LTCD are based on two central assumptions (Baltes et al. 1998):

(a) Cognitive development reflects the operation of two intertwined components, one biological and the other cultural. The specific definition and terminology regarding the two components varies across different LTCD (see Sect. 3). In general, the biological component is construed as an expression of the neurophysiological architecture of the mind as it evolved during biological evolution and unfolds during ontogeny. In contrast, the cultural component refers to bodies of knowledge available from and mediated through culture.

(b) During ontogeny, potential related to the biological component is *invested into* various cultural domains, thereby leading to the acquisition of culturally transmitted bodies of knowledge. A good example is the acquisition of reading and writing skills. Hence, at any point in time during development, two types of cognitive capacities can be distinguished: (i) the capacity to invest (i.e., to acquire new knowledge of various sorts) and (ii) the capacity to think and act on the basis of acquired knowledge.

## *2. Theoretical Background: the Lifespan Dynamics Between Biology and Culture*

Cognitive development participates in the general lifespan dynamics between biology and culture (see also *Lifespan Development*, *Theory of*). According to Baltes (1997), these dynamics can be characterized by three interrelated lifespan trends: (a) a decrease in evolutionary selection benefits; (b) a concomitant increase in the need for culture; and (c) a decrease in the efficacy of culture in reaching adaptive outcomes.

### *2.1 Decrease in Evolutionary Selection Benefits*

This proposition speaks to the biological component of cognition, and derives from an evolutionary perspective on the nature of the genome and its age-correlated changes in expression and biological potential. During evolution, the older the organism, the less the genome benefited from the genetic advantages associated with evolutionary selection. After maturity, and with age, the expressions and mechanisms of the genome lose in functional quality. This holds true even though some indirect positive evolutionary selection benefits may be carried into old age (e.g., through grandparenting). The age-associated diminution of evolutionary selection benefits and its implied association with an age-related loss of biological potential is further accentuated by the fact that fewer people reached old age in earlier times.

### *2.2 Increase in Need for Culture*

The second proposition summarizes the overall perspective on lifespan development associated with culture and culture-based processes. Among these cultural resources are physical structures, the world of economics as well as that of medical and physical technology, but also cognitive skills such as formal logic, literacy, and written documents. The argument for an age-related increase in the 'need' for culture has two parts. First, for human ontogeny to have reached increasingly high levels of functioning across historical time, whether in physical or psychological domains, there had to be a conjoint evolutionary increase in the richness and dissemination of the resources and 'opportunities' of culture. The second argument for the proposition relates to the biological weakening associated with age. That is, the older we are, the more we need culture-based resources to generate and maintain high levels of functioning. For instance, in old age, it generally takes more time and practice to attain the same amount of learning gains than in early adulthood (see next).

### *2.3 Decrease in the Efficiency of Culture*

The efficiency of cultural factors and resources in producing desired outcomes decreases with age, especially during the second half of life. There are three major causes for this age-related reduction in cultural efficiency. The first is age-related loss in biological potential. The second is related to the shape of *learning curves*, which express the process of knowledge acquisition in specified domains. Such curves generally start out steep and then reach an asymptote. Given that older individuals, on average, are more likely to find themselves in later phases of learning than younger individuals (i.e., closer to the asymptote), increasing amounts of effort and technology are needed to produce further gains. The third cause refers to negative consequences of earlier learning on later learning (i.e., *negative transfer*).

### *2.4 Consequences for LTCD*

In combination, the two core assumptions of LTCD and the general lifespan dynamics between biology and culture predict the presence of multidirectionality in cognitive lifespan development: the biological component of cognition is expected to decline after maturity, reflecting the decrease in evolutionary selec-

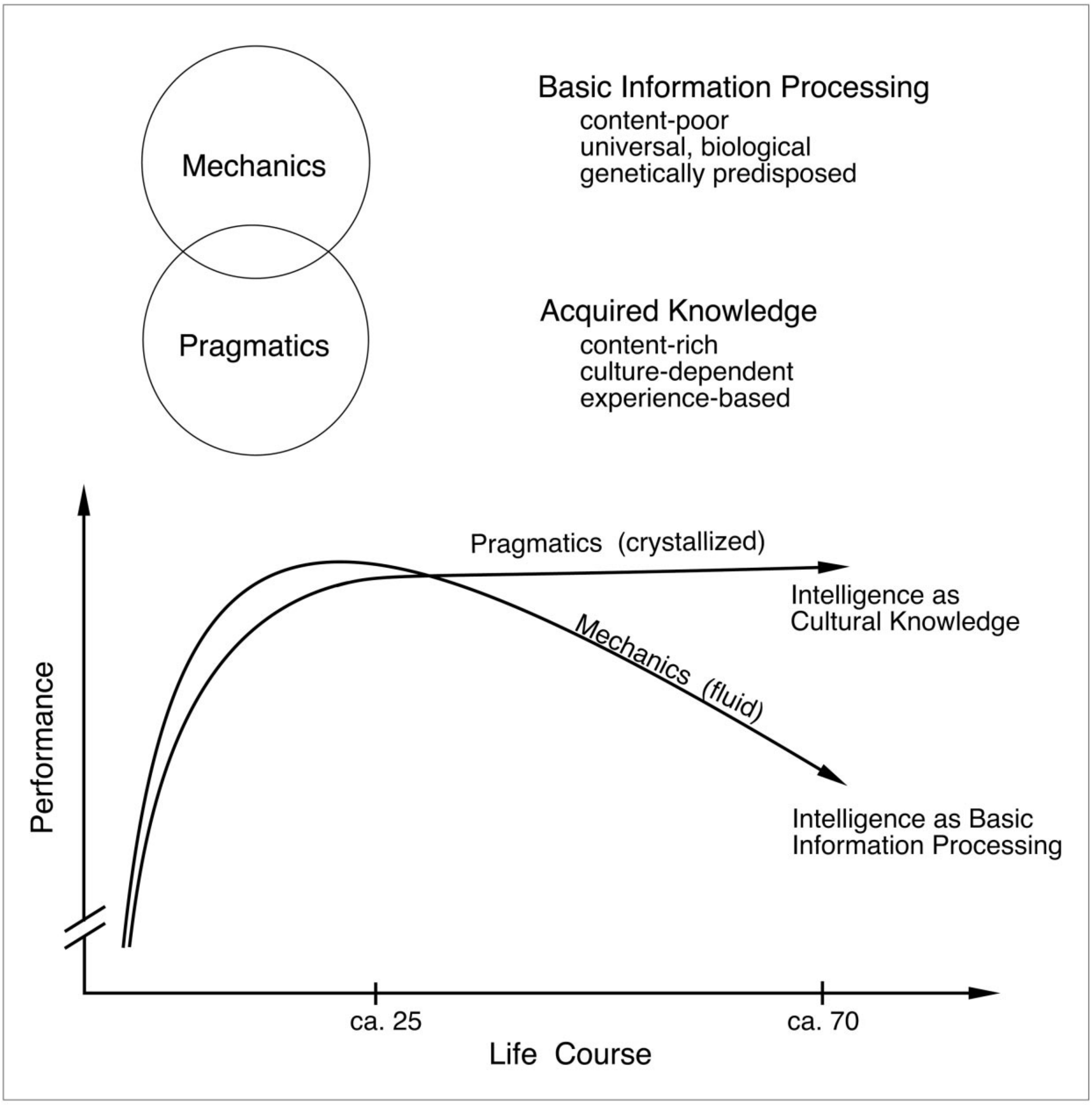


***Figure 1***
Lifespan theories of cognitive development posit two-component models of cognition. The top section defines the categories, the bottom section illustrates postulated lifespan trajectories (after Baltes et al. 1998; cf., Hebb 1949, Cattell 1971). In advanced old age, the trajectories show less and less differentiation (Lindenberger and Baltes 1997)

tion pressures with age. In contrast, the cultural component of cognition is expected to increase with age as long as knowledge maintenance and knowledge acquisition outweigh age-based losses in biological potential (see Fig. 1).

Moreover, any given cognitive performance can be portrayed as the combined outcome of biological and cultural systems of influence (Lindenberger and Baltes 1997). Age differences in skilled chess performance (Charness and Bosman 1990) illustrate this point. The mean age at which a world championship is first won is about 46 years for correspondence chess but about 30 years for tournament chess. In correspondence chess, players are permitted three days to deliberate a move; in tournament chess, deliberation averages three minutes per move. Conceivably, the difference in peak age reflects differences in the relative importance of task-relevant mechanisms with a strong biological component, such as speed of perception and working memory, and mechanisms with a strong cultural component, such as procedural and declarative knowledge about chess.

## 3. Variation in Terminology and Scope Among LTCD

### 3.1 Two-component LTCD

Two-component LTCD vary in terminology and scope (Baltes et al. 1998). As mentioned, Tetens (1777) was the first to propose an LTCD. His distinction between biology-based *absolute capacities* and culture-based *relative capacities* anticipated central ideas and findings regarding lifespan cognitive development, such as the investment relation and the divergence in age gradients between the two components.

Within the psychometric research tradition, the most influential LTCD is the theory of *fluid* and *crystallized intelligence* (*Gf–Gc theory*) introduced by Raymond B. Cattell (see *Cattell, Raymond Bernard (1905–98)*) and modified by John Horn (Cattell 1971, Horn 1989). Fluid intelligence represents the biological component; it is called fluid because it can be invested into various cultural domains. In contrast, crystallized intelligence represents the cultural component; it is called crystallized because it has solidified into knowledge. Gf–Gc theory summarizes a vast amount of empirical evidence obtained through *standardized testing* and *factor analysis*.

More recently, Paul Baltes (1987) also proposed a model with two components, the biology-based *mechanics* and the culture-based *pragmatics* of cognition. In comparison with the Gf–Gc distinction, the two-component model introduced by Baltes is broader in scope. For instance, in addition to the emphasis on individual differences and measurement precision inherited from Gf–Gc theory, the model seeks to integrate findings from cognitive psychology, evolutionary psychology, cultural psychology, cognitive neurosciences, and developmental biology (Baltes et al. 1998). Hebb's (1949) distinction between intelligence A (intellectual power) and intelligence B (intellectual products) resembles the mechanics–pragmatic distinction. Additional LTCD are mentioned in Baltes et al. (1998).

### 3.2 Structuralist (NeoPiagetian) LTCD

Two-component LTCD are functionalist in character. For instance, they emphasize the local nature of developmental adaptations during knowledge acquisition, selective specialization, and transfer. In contrast, *structuralist* LTCD posit that lifespan intellectual development follows a stage-like movement towards higher (more mature) forms of reasoning and thought (Labouvie-Vief 1982, Blanchard-Fields 1989). Building upon the theory of cognitive development formulated by Jean Piget, structuralist LTCD search for the emergence of one or more 'post-formal' or 'dialectical' stages of cognitive development after the advent of formal operations, the highest stage in Piaget's theory (see *Piaget, Jean (1896–1980)*). The conceptual description of these post-formal stages often connects personality development (e.g., generativity in the *Eriksonian* sense) with logical considerations (e.g., awareness and acceptance of contradiction). As a consequence of this particular linkage, the emergence of post-formal stages is expected to be accompanied by increments in reflexivity and general awareness for the human condition.

Generally, two-component, functionalist LTCD seem more amenable to operational definition and empirical investigation than structuralist LTCD (Baltes et al. 1998). For instance, from a functionalist perspective, the search for higher forms of reasoning can be redirected into a search for bodies of acquired knowledge with a high degree of generality and meaning.

The following sections focus on two-component LTCD. First, the mechanics–pragmatics distinction is elaborated in some detail. Select findings and hypotheses will be summarized thereafter.

## 4. Two-component Models of Cognition: the Mechanics–Pragmatics Distinction

### 4.1 The Mechanics of Cognition

In the mechanics of cognition, the predominant age-graded ontogenetic pattern is one of maturation, stability, and aging-induced decline. Age-based changes in this component early and late in ontogeny are assumed to be strongly influenced by genetic and other brain status-related factors, albeit in fundamentally different ways. Early in ontogeny (i.e., during embryogenesis, infancy, and early childhood), age-based changes in the mechanics primarily reflect the unfolding and active construction of more or less domain-specific and predisposed processing capabilities (Wellman and Gelman 1992). In contrast, negative changes in the mechanics of cognition late in life result from brain-related consequences of less effective phylogenetic selection pressures operating during this period.

The cognitive mechanics, then, reflect fundamental organizational properties of the central nervous system. In terms of psychological operations, these properties are indexed by the speed, accuracy, and coordination of elementary processing operations as assessed in tasks measuring the quality of information input, sensory and motor memory, discrimination, categorization, and selective attention, as well as reasoning ability in highly overlearned or novel domains.

### *4.2 The Pragmatics of Cognition*

In contrast to the mechanics, the pragmatics of the mind reveal the power of human agency and culture. Developmental changes in this component reflect the acquisition of culturally transmitted bodies of *declarative* and *procedural knowledge* that are made available to individuals in the course of *socialization*. Some of these socialization events are normative but specific to certain cultures (e.g., formal schooling), others are more universal (e.g., mentoring), and still others are idiosyncratic or person-specific (e.g., specialized ecological and professional knowledge). In all cases, the corresponding bodies of knowledge are represented both internally (e.g., *semantic networks*) and externally (e.g., books). Pragmatic knowledge systems are acquired during ontogeny but may build on evolutionarily prestructured, domain-specific knowledge (Siegler and Crowley 1994).

Compared with the mechanics, the pragmatics of cognition direct the attention of lifespan researchers towards the increasing significance of acquired knowledge in cognitive behavior (Ericsson and Lehmann 1996). Typical examples include reading and writing skills, educational qualifications, professional *expertise*, and varieties of everyday problem-solving, but also knowledge about the self and the meaning and conduct of life (Staudinger and Pasupathi 2000) (see *Wisdom*, *Psychology of*).

### *4.3 The Relation Between Mechanics and Pragmatics*

A common misunderstanding about two-component LTCD is that biological and cultural components are assumed to operate separately. As illustrated by the intersecting circles in Fig. 1, LTCD recognize that cognitive behavior reflects the joint operation of biological and cultural systems of influence, and posits that biological (mechanic) and cultural (pragmatic) development interact in complex and changing ways throughout life. During infancy and early childhood, the unfolding of the mechanics is dependent upon the acquisition of pragmatic knowledge. For instance, the ability of newborns to prefer the language spoken by their mothers during pregnancy over other languages has a strong biological component, but this component needs cultural specification (e.g., one specific language is preferred over another). Later in life, the acquisition and maintenance of pragmatic knowledge increasingly serve the function to buffer (circumvent) the negative consequences of mechanic decline. Moreover, at least in some cases, pragmatic knowledge is acquired as a compensatory reaction to losses in the mechanics (Freund et al. 1999). In agreement with Sect. 2, the buffering and compensatory functions of pragmatic knowledge increase in importance but decrease in efficiency with advancing age.

Another misunderstanding about the two-component model concerns its relation to the issue of *domain generality* versus *domain specificity*; that is, to the question whether a given set of cognitive mechanisms applies to a large or a small number of task domains. Here, the mechanics are often identified with *domain generality* in cognitive development, and the pragmatics with *domain specificity*. At first sight, this seems reasonable because acquired bodies of knowledge tend to be specialized (e.g., knowledge about chess), whereas mechanisms associated with basic learning capabilities tend to generalize across domains (e.g., the *law of reinforcement*). However, at closer inspection, the mapping is not so clear. First, certain components of the mechanics are dedicated to, or at least particularly important for, specific domains (e.g., infants' preference for human faces). Second, some bodies of acquired knowledge, such as *knowledge about the fundamental pragmatics of life* (with *wisdom* being its highest expression; see *Wisdom, Psychology of*), are general in the sense that their range of applicability is very broad. Therefore, the distinction between domain generality and domain specificity is correlated but not identical with the mechanics–pragmatics distinction.

## *5. Select Findings and Hypotheses Associated with LTCD*

LTCD attempt to integrate and generate research findings and hypotheses across different content domains and age periods. A few central examples may suffice for illustration; more can be found in Baltes et al. (1998).

### *5.1 Divergence of Mechanic and Pragmatic Age Gradients*

The most longstanding evidence in support of the mechanics–pragmatics distinctions is the difference between maintained and vulnerable intellectual abilities observed in lifespan studies of psychometric intelligence (Jones and Conrad 1933). Abilities that critically involve the mechanics, such as reasoning, memory, spatial orientation, and perceptual speed, generally show a pattern of monotonic and roughly linear decline during adulthood, with some further acceleration of decline in very old age. In contrast, predominantly pragmatic abilities, such as verbal knowledge and certain facets of numerical ability, remain stable or increase up to the sixth or seventh decade of life. They only start to evince some decline in very old age, when the mechanics fall below a certain threshold in most individuals.

### *5.2 Differentiation–Reintegration Hypothesis of Interindividual Differences in Intellectual Functioning Across the Lifespan*

As a general rule, the degree of covariation across different intellectual abilities, often represented as the prominence of a general factor (*g*) of intellectual functioning, appears to decrease from childhood to middle adulthood, and to increase again in very old age (Baltes and Lindenberger 1997, Lindenberger and Baltes 1997). This empirical regularity is well captured by assuming curvilinear age-based changes in the importance of domain-general mechanic constraints on cognitive performance, as formulated by the *differentiation–reintegration hypothesis* of intellectual lifespan development (for its origins, see Baltes et al. 1998; also *Intelligence: Central Conceptions and Psychometric Models*).

### *5.3 Malleability and Plasticity*

A central theme in *lifespan psychology* concerns the malleability, and especially optimization, of psychological functioning and behavior throughout all phases of life. The effects of cohort, historical period, and environmental change on age changes and age differences in cognitive performance are one indication of malleability (Schaie 1996). Experimental *testing-the-limits* procedures offer another, more direct way to explore age differences in upper limits of performance potential (Baltes and Kliegl 1992). In adulthood, cognitive plasticity continues to be present in cognitively healthy older adults, albeit to a lesser degree than in young adults. In fact, when pushed to the upper limits of performance in tasks which critically involve the mechanics, the performance distributions of young and old adults are close to non-overlapping (Baltes and Kliegl 1992). For the most part, cognitive plasticity reflects the acquisition of novel cognitive tools (e.g., the investment of existing mechanic potential), rather than an amelioration of the mechanic component itself.

### *5.4 Search for Basic Determinants of Mechanic Development*

Attempts have been made to identify domain-general mechanisms acting as pacemakers for lifespan changes in the mechanics of cognition. Among the most prominent constructs are *information processing rate*, *working memory capacity*, and the ability to suppress irrelevant information (*inhibition*). Supportive evidence has been gathered for each of the three constructs at both ends of the lifespan, especially with respect to information processing rate (Salthouse 1996). At the same time, all three constructs suffer from a lack of direct evidence at the physiological level and from difficulties in making differential predictions. A closer link to cognitive neurosciences and formal modeling approaches is expected to foster progress in this area of research (Li and Lindenberger 1999).

### *5.5 Relative (e.g., Rank Order) Stability and Level Stability in Intellectual Functioning Across the Lifespan*

Generally, relative stabilities computed after identical lapses of time show a strong increase in magnitude from middle childhood to adolescence into middle adulthood and early old age (Hertzog and Schaie 1986), followed by a probable decrease in old and very old age. According to LTCD, these age-based changes in relative stability need to be interpreted in conjunction with age-based changes in level (Molenaar et al. 1991). The specific prediction is that interindividual differences change more rapidly early in development because the intellectual repertoire is smaller but growing faster than at later points in ontogeny, thereby giving room for larger amounts of new variance per unit time (both environmental and genetic). Similarly, the preponderance of age-based losses in very old age may not only lead to decrements in level but also to a reshuffling of individual differences. Both predictions specify relations between changes in covariance and changes in mean level over time, and call for the use of complex statistical modeling techniques. In this respect, they point to the more general phenomenon of a close connection between conceptual and methodological advances in the context of LTCD.

## *6. Conclusion*

Compared with the large number and great diversity of cognitive-developmental theories about specific age periods (e.g., infancy), content domains (e.g., faces), and processes (e.g., recognition), LTCD form a small and relatively homogeneous set. One characteristic feature of this set is to articulate disparate bodies of knowledge about cognitive development with general propositions about the overall architecture of human ontogeny. The resulting bird's eye view on cognitive lifespan development stresses the variability and modifiability of human development at the inter- and intraindividual level, but it also stresses its invariant, age-dependent properties. The future role played by LTCD will depend on their utility for scholars working on more specific aspects of cognitive development, and on their ability to link the field of cognitive lifespan development to neighboring fields and disciplines.

*See also*: Adult Cognitive Development: Post-Piagetian Perspectives; Aging Mind: Facets and Levels of Analysis; Aging, Theories of; Cattell, Raymond Bernard (1905–98); Cognitive Aging; Education and Learning: Lifespan Perspectives; Lifespan Development, Theory of; Memory and Aging, Cognitive Psychology of; Wisdom, Psychology of

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U. Lindenberger

# Likelihood in Statistics

A statistical model for phenomena in the sciences or social sciences is a mathematical construct which associates a *probability* with each of the possible outcomes. If the data are discrete, such as the numbers of people falling into various classes, the model will be a discrete probability distribution, but if the data consist of measurements or other numbers that may take any values in a continuum, the model will be a continuous probability distribution. When two different models, or perhaps two variants of the same model differing only in the value of some adjustable parameter(s), are to be compared as explanations for the same observed outcome, the probability of obtaining this particular outcome can be calculated for each and is then known as the *likelihood* for the model or parameter value(s) given the data. This article enlarges on the definition of likelihood, discusses its properties and uses, and relates it to other approaches to statistical inference.

## 1. *Probability and Likelihood Distinguished*

Probabilities and likelihood are easily (and frequently) confused, and it is for this reason that in 1921 R.A.Fisher introduced the new word: 'What we can




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