

Ethash was Ethereum's proof-of-work mining algorithm. Proof-of-work has now been **switched off entirely** and Ethereum is now secured using [proof-of-stake](#) instead. Read more on [The Merge](#), [proof-of-stake](#) and [staking](#). This page is for historical interest!

[Ethash](#) is a modified version of the [Dagger-Hashimoto](#) algorithm. Ethash proof-of-work is [memory hard](#), which was thought to make the algorithm ASIC resistant. Ethash ASICs were eventually developed but GPU mining was still a viable option until proof-of-work was switched off. Ethash is still used to mine other coins on other non-Ethereum proof-of-work networks.

How does Ethash work? {#how-does-ethash-work}

Memory hardness is achieved with a proof of work algorithm that requires choosing subsets of a fixed resource dependent on the nonce and block header. This resource (a few gigabytes in size) is called a DAG. The DAG is changed every 30000 blocks, a ~125-hour window called an epoch (roughly 5.2 days) and takes a while to generate. Since the DAG only depends on block height, it can be pre-generated, but if it's not the client needs to wait until the end of this process to produce a block. If clients do not pre-generate and cache DAGs ahead of time the network may experience massive block delay on each epoch transition. Note that the DAG does not need to be generated for verifying the proof-of-work essentially allowing for verification with both low CPU and small memory.

The general route that the algorithm takes is as follows:

1. There exists a **seed** which can be computed for each block by scanning through the block headers up until that point.
2. From the seed, one can compute a **16 MB pseudorandom cache**. Light clients store the cache.
3. From the cache, we can generate a **1 GB dataset**, with the property that each item in the dataset depends on only a small number of items from the cache. Full clients and miners store the dataset. The dataset grows linearly with time.
4. Mining involves grabbing random slices of the dataset and hashing them together. Verification can be done with low memory by using the cache to regenerate the specific pieces of the dataset that you need, so you only need to store the cache.

The large dataset is updated once every 30000 blocks, so the vast majority of a miner's effort will be reading the dataset, not making changes to it.

Definitions {#definitions}

We employ the following definitions:

```
WORD_BYTES = 4 # bytes in word DATASET_BYTES_INIT = 2**30 # bytes in dataset at genesis DATASET_BYTES_GROWTH = 2**23 # dataset growth per epoch
CACHE_BYTES_INIT = 2**24 # bytes in cache at genesis CACHE_BYTES_GROWTH = 2**17 # cache growth per epoch
CACHE_MULTIPLIER=1024 # Size of the DAG relative to the cache EPOCH_LENGTH = 30000 # blocks per epoch
MIX_BYTES = 128 # width of mix HASH_BYTES = 64 # hash length in bytes DATASET_PARENTS = 256 # number of parents of each dataset element
CACHE_ROUNDS = 3 # number of rounds in cache production ACCESSES = 64 # number of accesses in hashimoto loop
```

The use of 'SHA3' {#sha3}

Ethereum's development coincided with the development of the SHA3 standard, and the standards process made a late change in the padding of the finalized hash algorithm, so that Ethereum's "sha3_256" and "sha3_512" hashes are not standard sha3 hashes, but a variant often referred to as "Keccak-256" and "Keccak-512" in other contexts. See discussion, e.g. [here](#), [here](#), or [here](#).

Please keep that in mind as "sha3" hashes are referred to in the description of the algorithm below.

Parameters {#parameters}

The parameters for Ethash's cache and dataset depend on the block number. The cache size and dataset size both grow linearly; however, we always take the highest prime below the linearly growing threshold in order to reduce the risk of

accidental regularities leading to cyclic behavior.

```
```python def get_cache_size(block_number): sz = CACHE_BYTES_INIT + CACHE_BYTES_GROWTH * (block_number // EPOCH_LENGTH) sz -= HASH_BYTES while not isprime(sz / HASH_BYTES): sz -= 2 * HASH_BYTES return sz

def get_full_size(block_number): sz = DATASET_BYTES_INIT + DATASET_BYTES_GROWTH * (block_number // EPOCH_LENGTH) sz -= MIX_BYTES while not isprime(sz / MIX_BYTES): sz -= 2 * MIX_BYTES return sz ```
```

Tables of dataset and cache size values are provided in the appendix.

## Cache generation {#cache-generation}

Now, we specify the function for producing a cache:

```
```python def mkcache(cache_size, seed): n = cache_size // HASH_BYTES

# Sequentially produce the initial dataset
o = [sha3_512(seed)]
for i in range(1, n):
    o.append(sha3_512(o[-1]))

# Use a low-round version of randmemohash
for _ in range(CACHE_ROUNDS):
    for i in range(n):
        v = o[i][0] % n
        o[i] = sha3_512(map(xor, o[(i-1+n) % n], o[v]))

return o

```
```

The cache production process involves first sequentially filling up 32 MB of memory, then performing two passes of Sergio Demian Lerner's *RandMemoHash* algorithm from [Strict Memory Hard Hashing Functions \(2014\)](#). The output is a set of 524288 64-byte values.

## Data aggregation function {#data-aggregation-function}

We use an algorithm inspired by the [FNV hash](#) in some cases as a non-associative substitute for XOR. Note that we multiply the prime with the full 32-bit input, in contrast with the FNV-1 spec which multiplies the prime with one byte (octet) in turn.

```
```python FNV_PRIME = 0x01000193

def fnv(v1, v2): return ((v1 * FNV_PRIME) ^ v2) % 2**32 ```
```

Please note, even the yellow paper specifies fnv as $v1 * (FNV_PRIME \wedge v2)$, all current implementations consistently use the above definition.

Full dataset calculation {#full-dataset-calculation}

Each 64-byte item in the full 1 GB dataset is computed as follows:

```
python def calc_dataset_item(cache, i): n = len(cache) r = HASH_BYTES // WORD_BYTES # initialize the mix mix = copy.copy(cache[i % n]) mix[0] ^= i mix = sha3_512(mix) # fnv it with a lot of random cache nodes based on i for j in range(DATASET_PARENTS): cache_index = fnv(i ^ j, mix[j % r]) mix = map(fnv, mix, cache[cache_index % n]) return sha3_512(mix)
```

Essentially, we combine data from 256 pseudorandomly selected cache nodes, and hash that to compute the dataset node. The entire dataset is then generated by:

```
python def calc_dataset(full_size, cache): return [calc_dataset_item(cache, i) for i in range(full_size // HASH_BYTES)]
```

Main loop {#main-loop}

Now, we specify the main "hashimoto"-like loop, where we aggregate data from the full dataset in order to produce our final value for a particular header and nonce. In the code below, `header` represents the SHA3-256 *hash* of the RLP representation of a *truncated* block header, that is, of a header excluding the fields **mixHash** and **nonce**. `nonce` is the eight bytes of a 64 bit unsigned integer in big-endian order. So `nonce[::-1]` is the eight-byte little-endian representation of that value:

```
python def hashimoto(header, nonce, full_size, dataset_lookup): n = full_size / HASH_BYTES w = MIX_BYTES // WORD_BYTES mixhashes = MIX_BYTES / HASH_BYTES # combine header+nonce into a 64 byte seed s = sha3_512(header + nonce[::-1]) # start the mix with replicated s mix = [] for _ in range(MIX_BYTES / HASH_BYTES): mix.extend(s) # mix in random dataset nodes for i in range(ACCESSES): p = fnv(i ^ s[0], mix[i % w]) % (n // mixhashes) * mixhashes newdata = [] for j in range(MIX_BYTES / HASH_BYTES): newdata.extend(dataset_lookup(p + j)) mix = map(fnv, mix, newdata) # compress mix cmix = [] for i in range(0, len(mix), 4): cmix.append(fnv(fnv(fnv(mix[i], mix[i+1]), mix[i+2]), mix[i+3])) return { "mix digest": serialize_hash(cmix), "result": serialize_hash(sha3_256(s+cmix)) }
```

```
def hashimoto_light(full_size, cache, header, nonce): return hashimoto(header, nonce, full_size, lambda x: calc_dataset_item(cache, x))
```

```
def hashimoto_full(full_size, dataset, header, nonce): return hashimoto(header, nonce, full_size, lambda x: dataset[x]) ``
```

Essentially, we maintain a "mix" 128 bytes wide, and repeatedly sequentially fetch 128 bytes from the full dataset and use the `fnv` function to combine it with the mix. 128 bytes of sequential access are used so that each round of the algorithm always fetches a full page from RAM, minimizing translation lookaside buffer misses which ASICs would theoretically be able to avoid.

If the output of this algorithm is below the desired target, then the nonce is valid. Note that the extra application of `sha3_256` at the end ensures that there exists an intermediate nonce which can be provided to prove that at least a small amount of work was done; this quick outer PoW verification can be used for anti-DDoS purposes. It also serves to provide statistical assurance that the result is an unbiased, 256-bit number.

Mining {#mining}

The mining algorithm is defined as follows:

```
python def mine(full_size, dataset, header, difficulty): # zero-pad target to compare with hash on the same digit target = zpad(encode_int(2**256 // difficulty), 64)[::-1] from random import randint nonce = randint(0, 2**64) while hashimoto_full(full_size, dataset, header, nonce) > target: nonce = (nonce + 1) % 2**64 return nonce
```

Defining the seed hash {#seed-hash}

In order to compute the seed hash that would be used to mine on top of a given block, we use the following algorithm:

```
python def get_seedhash(block): s = '\x00' * 32 for i in range(block.number // EPOCH_LENGTH): s = serialize_hash(sha3_256(s)) return s
```

Note that for smooth mining and verifying, we recommend pre-computing future seedhashes and datasets in a separate thread.

Further reading {#further-reading}

Know of a community resource that helped you? Edit this page and add it!

Appendix {#appendix}

The following code should be prepended if you are interested in running the above python spec as code.

```
python import sha3, copy
```

Assumes little endian bit ordering (same as Intel

architectures)

```
def decode_int(s): return int(s[::-1].encode('hex'), 16) if s else 0

def encode_int(s): a = "%x" % s return " " if s == 0 else ('0' * (len(a) % 2) + a).decode('hex')[::-1]

def zpad(s, length): return s + '\x00' * max(0, length - len(s))

def serialize_hash(h): return ".join([zpad(encode_int(x), 4) for x in h])

def deserialize_hash(h): return [decode_int(h[i:i+WORD_BYTES]) for i in range(0, len(h), WORD_BYTES)]

def hash_words(h, sz, x): if isinstance(x, list): x = serialize_hash(x) y = h(x) return deserialize_hash(y)

def serialize_cache(ds): return ".join([serialize_hash(h) for h in ds])

serialize_dataset = serialize_cache
```

sha3 hash function, outputs 64 bytes

```
def sha3_512(x): return hash_words(lambda v: sha3.sha3_512(v).digest(), 64, x)

def sha3_256(x): return hash_words(lambda v: sha3.sha3_256(v).digest(), 32, x)

def xor(a, b): return a ^ b

def isprime(x): for i in range(2, int(x**0.5)): if x % i == 0: return False return True ``
```

Data Sizes {#data-sizes}

The following lookup tables provide approximately 2048 tabulated epochs of data sizes and cache sizes.

```
``python def get_datasize(block_number): return data_sizes[block_number // EPOCH_LENGTH]
```

```
def get_cachesize(block_number): return cache_sizes[block_number // EPOCH_LENGTH]
```

```
data_sizes = [ 1073739904, 1082130304, 1090514816, 1098906752, 1107293056, 1115684224, 1124070016,
1132461952, 1140849536, 1149232768, 1157627776, 1166013824, 1174404736, 1182786944, 1191180416, 1199568512,
1207958912, 1216345216, 1224732032, 1233124736, 1241513344, 1249902464, 1258290304, 1266673792, 1275067264,
1283453312, 1291844992, 1300234112, 1308619904, 1317010048, 1325397376, 1333787776, 1342176128, 1350561664,
1358954368, 1367339392, 1375731584, 1384118144, 1392507008, 1400897408, 1409284736, 1417673344, 1426062464,
1434451072, 1442839168, 1451229056, 1459615616, 1468006016, 1476394112, 1484782976, 1493171584, 1501559168,
1509948032, 1518337664, 1526726528, 1535114624, 1543503488, 1551892096, 1560278656, 1568669056, 1577056384,
1585446272, 1593831296, 1602219392, 1610610304, 1619000192, 1627386752, 1635773824, 1644164224, 1652555648,
1660943488, 1669332608, 1677721216, 1686109312, 1694497664, 1702886272, 1711274624, 1719661184, 1728047744,
1736434816, 1744829056, 1753218944, 1761606272, 1769995904, 1778382464, 1786772864, 1795157888, 1803550592,
1811937664, 1820327552, 1828711552, 1837102976, 1845488768, 1853879936, 1862269312, 1870656896, 1879048064,
1887431552, 1895825024, 1904212096, 1912601216, 1920988544, 1929379456, 1937765504, 1946156672, 1954543232,
1962932096, 1971321728, 1979707264, 1988093056, 1996487552, 2004874624, 2013262208, 2021653888, 2030039936,
2038430848, 2046819968, 2055208576, 2063596672, 2071981952, 2080373632, 2088762752, 2097149056, 2105539712,
2113928576, 2122315136, 2130700672, 2139092608, 2147483264, 2155872128, 2164257664, 2172642176, 2181035392,
2189426048, 2197814912, 2206203008, 2214587264, 2222979712, 2231367808, 2239758208, 2248145024, 2256527744,
2264922752, 2273312128, 2281701248, 2290086272, 2298476672, 2306867072, 2315251072, 2323639168, 2332032128,
2340420224, 2348808064, 2357196416, 2365580416, 2373966976, 2382363008, 2390748544, 2399139968, 2407530368,
2415918976, 2424307328, 2432695424, 2441084288, 2449472384, 2457861248, 2466247808, 2474637184, 2483026816,
2491414144, 2499803776, 2508191872, 2516582272, 2524970368, 2533359232, 2541743488, 2550134144, 2558525056,
2566913408, 2575301504, 2583686528, 2592073856, 2600467328, 2608856192, 2617240448, 2625631616, 2634022016,
```

2642407552, 2650796416, 2659188352, 2667574912, 2675965312, 2684352896, 2692738688, 2701130624, 2709518464, 2717907328, 2726293376, 2734685056, 2743073152, 2751462016, 2759851648, 2768232832, 2776625536, 2785017728, 2793401984, 2801794432, 2810182016, 2818571648, 2826959488, 2835349376, 2843734144, 2852121472, 2860514432, 2868900992, 2877286784, 2885676928, 2894069632, 2902451584, 2910843008, 2919234688, 2927622784, 2936011648, 2944400768, 2952789376, 2961177728, 2969565568, 2977951616, 2986338944, 2994731392, 3003120256, 3011508352, 3019895936, 3028287104, 3036675968, 3045063808, 3053452928, 3061837696, 3070228352, 3078615424, 3087003776, 3095394944, 3103782272, 3112173184, 3120562048, 3128944768, 3137339264, 3145725056, 3154109312, 3162505088, 3170893184, 3179280256, 3187669376, 3196056704, 3204445568, 3212836736, 3221224064, 3229612928, 3238002304, 3246391168, 3254778496, 3263165824, 3271556224, 3279944576, 3288332416, 3296719232, 3305110912, 3313500032, 3321887104, 3330273152, 3338658944, 3347053184, 3355440512, 3363827072, 3372220288, 3380608384, 3388997504, 3397384576, 3405774208, 3414163072, 3422551936, 3430937984, 3439328384, 3447714176, 3456104576, 3464493952, 3472883584, 3481268864, 3489655168, 3498048896, 3506434432, 3514826368, 3523213952, 3531603584, 3539987072, 3548380288, 3556763264, 3565157248, 3573545344, 3581934464, 3590324096, 3598712704, 3607098752, 3615488384, 3623877248, 3632265856, 3640646528, 3649043584, 3657430144, 3665821568, 3674207872, 3682597504, 3690984832, 3699367808, 3707764352, 3716152448, 3724541056, 3732925568, 3741318016, 3749706368, 3758091136, 3766481536, 3774872704, 3783260032, 3791650432, 3800036224, 3808427648, 3816815488, 3825204608, 3833592704, 3841981568, 3850370432, 3858755968, 3867147904, 3875536256, 3883920512, 3892313728, 3900702592, 3909087872, 3917478784, 3925868416, 3934256512, 3942645376, 3951032192, 3959422336, 3967809152, 3976200064, 3984588416, 3992974976, 4001363584, 4009751168, 4018141312, 4026530432, 4034911616, 4043308928, 4051695488, 4060084352, 4068472448, 4076862848, 4085249408, 4093640576, 4102028416, 4110413696, 4118805632, 4127194496, 4135583104, 4143971968, 4152360832, 4160746112, 4169135744, 4177525888, 4185912704, 4194303616, 4202691968, 4211076736, 4219463552, 4227855488, 4236246656, 4244633728, 4253022848, 4261412224, 4269799808, 4278184832, 4286578048, 4294962304, 4303349632, 4311743104, 4320130432, 4328521088, 4336909184, 4345295488, 4353687424, 4362073472, 4370458496, 4378852736, 4387238528, 4395630208, 4404019072, 4412407424, 4420790656, 4429182848, 4437571456, 4445962112, 4454344064, 4462738048, 4471119232, 4479516544, 4487904128, 4496289664, 4504682368, 4513068416, 4521459584, 4529846144, 4538232704, 4546619776, 4555010176, 4563402112, 4571790208, 4580174464, 4588567936, 4596957056, 4605344896, 4613734016, 4622119808, 4630511488, 4638898816, 4647287936, 4655675264, 4664065664, 4672451968, 4680842624, 4689231488, 4697620352, 4706007424, 4714397056, 4722786176, 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